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# Do firms cooperate in R&D persistently? Evidence from Spain

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**Abstract:** This study analyse the persistence in the decision to engage in R&D cooperation agreements using a panel of Spanish innovative firms for the period 2002-2010. For this purpose we estimate a dynamic random effects probit accounting for unobserved heterogeneity and initial conditions. The empirical analysis is then expanded by estimating a multinomial probit model to predict the relative effect of firms' characteristics on R&D cooperation profiles: the persistent co-operator, the sporadic co-operator and the recurrent non co-operator. The results evidence that there is true state dependence in the R&D cooperation behaviour of firm, that is the probability of engaging in R&D cooperation is highly influenced by past R&D cooperation agreements. Furthermore, our findings stress the important role of public funding, especially European subsidies, as a mechanism to encourage persistent R&D cooperation activities. A higher importance attributed to public sources for innovation, the use of protection methods, firm size and belonging to a group of enterprises also positively affects the probability of being a persistent co-operator and not the sporadic ones.

**Keywords:** R&D cooperation; Persistence; Innovative Spanish firms; Dynamic random effects probit model; Multinomial probit model
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## 1. Introduction

Nowadays, thanks to the globalization and the rapid diffusion of technological knowledge, firms are forced to accelerate their rhythm of innovation and to expand their technological capabilities. Innovation has become a key element to maintain competitiveness, and therefore, the position in a given market. Firms that want to increase their technological capabilities can make it through different mechanisms, either through internal efforts in R&D or through external activities in R&D such as hiring or cooperating. In particular, R&D cooperation is a strategy of knowledge sharing and transfer across firms that has increased importantly in recent decades.

In this sense, empirical contributions on the study of the strategies of R&D cooperation have expanded significantly in recent years. Some of these studies have shown, among other results, that R&D cooperation with other firms or institutions has a positive and significant effect on firm's performance (Miotti and Sachwald, 2003; Belderbos et al., 2004a; Lööf and Broström, 2008; Aschoff and Schmidt, 2008)[1]. Despite the extensive literature on R&D cooperation and the idea that cooperation influences positively on the innovative performance and productivity of firms, little attention has been paid in the persistence with which this type of agreements are carried out. This paper aims to provide empirical evidence on this issue. Most previous studies have examined the simple occurrence or existence of R&D cooperation, but it is clear that the use of this strategy as a way to undertake innovation activities may be more or less durable in time.

Innovation is the result of a dynamic process, which involves relationships both short and long term. It is generally accepted that technological advances cannot take place without systematic involvement in R&D (Mañez et al., 2009) and therefore, those firms for which cooperation is one of the main ways to access knowledge and carry out innovation activities, also need to be persistent in their cooperation agreements. Moreover, empirical knowledge about the dynamics in firms' cooperation behaviour is important from both a policy and firm's management perspective. Over the past few decades, public support policies have explicitly encouraged the formation of cooperation agreements in R&D and innovation

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[1] According to the theoretical work of D'Aspremont and Jacquemin (1998), cooperation may even have a positive effect on social welfare. Nonetheless, it has also been pointed that welfare could be reduced if firms collude in output and hence, alliance strategies should not be supported if they involve product market collusion (Greenlee and Cassiman, 1999; Goeree and Helland, 2010).

projects. Designing policies more effective should be at least in part aimed at activities that exhibit state dependence as it might suggest that such arrangements are relatively more successful. State dependence behaviour in R&D cooperation implies that policies measures that aim to encourage R&D cooperation such as government support programs are expected to have a greater impact because they do not only affect current cooperation agreements but are also more likely to induce continuous arrangements with other firms or research institutions. Moreover, understanding the determinants of the persistence of firms in undertaking agreements of collaboration would allow policy makers to focus resources on firms “survival-winners” and avoid wasting resources on firms “survival-losers”. Likewise, this empirical evidence should also help firms in their decisions to cooperate or not and the effort that should be devoted to it. On the other hand, the persistence in cooperation activities allows firms the formation of know-how knowledge, which involves information about who knows what and who knows what to do, as well as the social ability to co-operate and communicate with different partners (Lundvall, 2004).

From our knowledge, Belderbos et al. (2011) is the first to systematically explore the persistent character of alliance strategies with different types of partners. They follow the definition of persistence as “state dependence” from Heckman (1981). Using a data set on innovative Dutch firms, these authors test the hypothesis that being engaged in past alliance activities increases the probability to be engaged in these activities currently. Nevertheless, the authors do not control for unobserved individual heterogeneity because they did not find the panel-level variance component to be significant and hence, focus their results on a pooled multivariate model.

Bearing the above in mind, this paper contributes to the literature by examining, firstly, whether firms establish agreements of cooperation persistently as a strategy for carrying out their innovation activities and, secondly, by analysing specifically the factors leading to such persistence. This paper constitutes a dynamic approach to cooperation persistence, taking into account the unobserved individual heterogeneity and handling the initial conditions problem.

With this aim, we use a representative sample of Spanish firms for the period 2002-2010. The dataset is drawn from the Technological Innovation Panel (PITEC), a survey constructed on the basis of the annual Spanish responses to the Community Innovation Survey (CIS) and that provides detailed information at the firm level on innovative activities of Spanish companies.

Our estimation strategy consists of two steps. First, we estimate a dynamic random effects probit model in order to analyse if R&D cooperation is persistent at the firm level. Secondly, we apply a multinomial probit model to attempt to identify what drives R&D cooperation in a continuous way. This latter model permits to predict the relative effect of firms' characteristics on R&D cooperation profiles: the persistent co-operator, the sporadic co-operator and the recurrent non co-operator.

After this introduction, Section 2 proceeds with the literature review on the topic of the persistence in R&D cooperation activities. Section 3 describes the database used and shows some descriptive statistics. In Section 4 we study the persistence of R&D cooperation and in Section 5 we investigate the factors driving the persistence of firms in R&D cooperation. Finally, we present the main conclusions of the paper in Section 6.

## 2. Why R&D cooperation should exhibit persistence at the firm level?

While most studies on R&D cooperation strategies have examined the determinants of carrying out this strategy and their consequences on the firm's performance in a single point in time, the dynamics of R&D cooperation behaviour has been relatively ignored. In contrast, there has been an important amount of literature on the dynamic character of innovation itself, and in particular, on the persistence of innovation (Cefis, 2003; Mañez-Castillejo et al., 2009; Peters, 2009; Raymond et al., 2010).

Most studies investigating persistence of innovation have found evidence in favour of state dependence in the decision to innovate using dynamic discrete choice models or survival analysis. Nevertheless, the degree of persistence has depended among other things on how the authors measure innovation and if the firm unobserved heterogeneity have been taken into account. For instance, Geroski et al. (1997), Cefis and Orsenigo (2001) and Cefis (2003) using patent data and/or major innovations as measure of innovation showed a low degree of persistence in the patent activities. On the contrary, in studies using R&D and innovation data persistence in innovation activities is found to be high (Duguet and Monjon, 2002; Mañez-Castillejo et al., 2009; Peters, 2009). Raymond et al. (2010) emphasize that the persistence may be spurious and its existence can be ascertained only after accounting for individual effects and handling properly the initial conditions problems. Once this is done, these authors find a significant persistence in the occurrence of innovation in high-tech industries, while no such evidence is found in the low-tech industries. In general, the method used to examine innovation persistence consists in modelling the probability of a firm to innovate as a function of the lagged dependent variable (i.e. whether or not the firm innovated in a previous period) and other control variables. Innovation persistence occurs when the lagged innovation variable has a positive and significant sign (Clausen et al. 2011).

By contrast, in this paper we study one of the different mechanisms used by firms to carry out innovation activities, in particular, to what extent firms undertake R&D cooperation activities in a persistent way. As stated by Cefis and Orsenigo (2001) sustained innovative performance is generated and has to be supported by systematic and continuous processes of accumulation of resources and competencies over time. In this sense, we consider that the issue of persistence in R&D cooperation activities is relevant in the context how systematically firms using this strategy to access knowledge and resources to carry out innovation activities, which can be behind the traditional issue of whether or not, and to what extent, innovation is persistent. According to Clausen, et al. (2011), firms have different innovation strategies, and such strategies constitute an important source of persistent innovative behaviour.

For the best of our knowledge, Belderbos, et al. (2011) is the only one that analyses the persistence in the decision to cooperate using Dutch CIS data. They find evidence supporting the hypothesis that cooperation is persistent, that is, past engagement in alliances with a partner type predicts the propensity to be engaged in this type of alliance currently. This evidence was based on a pooled multivariate probit model because the panel-level variance component was not found relevant for the Dutch case.

Basically, we could point out three main reasons why some firms are expected to be persistent cooperators in R&D. The first is based on the hypothesis of "success-breeds-success". The idea is that successful R&D cooperation projects positively affects the conditions for further cooperation agreements in subsequent years. Firms tend to establish routines that are associated with positive performances, and are, therefore, replicated and perpetuated without drastic changes, leading to path dependency in their behaviour and strategy (Cyert and March, 1963; Nelson and Winter, 1982; Levitt and March, 1988; Belderbos et al., 2011). Thereby, firms gaining positive returns from innovations made in cooperation with other firms or institutions are keener to continue conducting this cooperative strategy than firms without a relative experience in this kind of activities. Furthermore, experience in cooperation may make firms more attractive as partners as they would be better able to generate value from partnerships (Gulati, 1995).

A second reason lies in the fact that cooperation agreements involve costs that may not be recoverable. Firms need to incur start-up costs for establishing cooperation agreements (for instance, costs related to searching, training and adapting to the partner of cooperation) and sometimes require a relatively large initial investment. This kind of costs can be considered, at least partly, as sunk costs (Sutton, 1991) and entail barriers to entry into and exit from cooperation projects. Firms involved in established cooperation agreements should better not stop cooperating in order to increase the probability of recovering their initial investments and gain from positive results from such agreements. As is pointed by Clausen et al. (2011), strategic alliances in which knowledge is jointly developed between firms, interactions between customers and suppliers or cooperation with research institutions may have important sunk costs and may, therefore, be more durable.

A third explanation focuses on knowledge accumulation. By cooperating firms acquire a set of capabilities and knowledge stocks which is well known as “learning by doing” and as a consequence, the probability of establishing future cooperation projects increases. Thanks to stable cooperation alliances, firms can obtain benefits by learning about their partner specific areas of specialization. In addition, a greater degree of trust between firms cooperating continuously is reached, which is a basic requisite for a successful alliance (Nooteboom, 2004). Experience in cooperation allows firm to obtain quite specialised competencies and to find the most reliable experts, forming a source of information on potential partners over time. This learning is also related to the concept of “learning by interacting” which points to how interaction in innovation enhances the relationship with external partners (Lundvall, 1988; Lundvall, 2004; Jensen et al. 2007).

The reasons above can lead to state dependence which is determined by past R&D cooperation experiences of firms, that is, the decision to cooperate in one period might affect the probability of cooperating in subsequent periods. Heckman (1981) refers to this phenomenon as true state dependence and it is captured in the lagged dependent variable. But it is also argued that there may be a spurious state dependence when unobserved individual differences (such as managerial abilities, risk attitudes or stock of tacit knowledge) are correlated over time and, if these differences are not properly controlled for in the estimation.

In this way, previous experience may appear to be a determinant of future experience solely because it captures the temporally persistent unobserved characteristics that determine the different choices. All in all, in the next sections we will study the phenomenon of persistence in the firms' decisions to engage in cooperation agreements as a way to carry out innovation activities, attempting to control for the presence of unobserved individual heterogeneity. In addition, we try specifically to predict the relative effect of firms' characteristics on such R&D cooperation persistence.

## 3. Data and variables in the empirical models

### 3.1 Dataset and some descriptive on the persistence of cooperation

The database used in this research is the Technological Innovation Panel (PITEC)[2], produced jointly by the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT) and the Cotec Foundation. The data come from different successive waves of the Spanish Innovation Survey conducted every year by the INE, which in turn is based on the Community Innovation Survey (CIS). An important advantage of using this database is that it allows us to study different issues related to the innovation activities of Spanish manufacturing and service firms over time as it is specifically designed to analyse technological activities. Given the specific aim of this study and because the questions about cooperation are asked in a three-year period, i.e. the survey asks whether or not the firm cooperated in the period between t-2 and t, we consider four waves of the PITEC: 2004 (wave 2002-2004), 2006 (wave 2004-2006), 2008 (wave 2006-2008) and 2010 (wave 2008-2010). Our data covering the period 2002-2010 allow us to observe firms' R&D cooperation behaviour over different phases of the business cycle.

A cleaning process[3] has been carried out and only those firms belonging to the industrial and service sectors, with at least ten employees and positive sales have been taken into account. In addition, since we are interested in the persistence of R&D cooperation activities, our analysis is restricted to firms engaging in innovative activities[4] for which technology collaboration is relevant. We distinguish two panel data sets. The first one is an unbalanced panel comprising

[2] This database is available to the public at http://icono.fecyt.es/PITEC/Paginas/por_que.aspx

[3] Firms that report confidentiality issues, mergers, closures, employment incidents and so on are eliminated.

[4] That is, firms that have introduced innovations in products or processes, or who were undertaking innovation activities during the analysed period or abandoned them.

all firms that are present in at least two consecutive waves[5]; and the second one is the balanced sub-sample. Both of them are needed for estimation purposes: the former is used to analyse if there is persistence in the cooperative behaviour of firms in the innovation activities, and the latter to analyse the factors driving cooperation persistence profiles (the persistent co-operator, the sporadic co-operator and the recurrent non co-operator). In Table 1 we show some characteristics of the two data sets.

[Insert Table 1 around here]

In each PITEC survey, for a three-year period, the firm is asked if it had any cooperation agreement with other firms or institutions on its innovation activities. Based on this question, we define the *cooperation* variable as an indicator variable which takes the value 1 if the firm decided to cooperate and zero otherwise[6]. Table 2 reports the transition probabilities of engaging in R&D cooperation agreements between periods t-1 and t, t-2 and t and t-3 and t for both the unbalanced and the balanced panels. For instance, in the unbalanced panel, nearly 71% of the cooperators in one wave persisted in cooperation in the subsequent wave, that is, after two to four years, while 29% stopped their arrangements. Regarding the non-cooperators about 84% remained in this status in the following wave and 16% change their status engaging into agreements of cooperation in the subsequent period. The corresponding figures are 73% vs. 27% and 83% vs. 17% in the balanced panel. Therefore, it turns out that the probability of cooperating in period t was about 55 percentage points higher for previous co-operators than for previous non-cooperators, showing a considerable persistence in cooperation activities from year to year. Despite the probability of permanence in the same state decreases as the period of observation extends, the last transition matrices (t-3 and t) still show a high level of persistence in the decisions to engage in R&D cooperation: nearly 57% of co-operators and 73% of non-cooperators remain in their initial state after six to eight years, with very similar figures for the balanced panel.

[Insert Table 2 around here]

[5] Using the unbalanced panel allows us to obtain more precise estimates as a higher number of observations and for a greater variety of firms are considered. Additionally also we control partly for survivorship biases as firms are allowed to enter and exit the sample at any period.
[6] Note that a lag of this variable refers to two to four years, two lags refer to four to six years and so on.

### 3.2 Variables

For the first purpose of our study, i.e. to analyse if the R&D cooperation decision is persistent at the firm level, the binary variable *cooperation* defined above is the dependent variable. We follow the standard modelling procedure for analyzing (innovation) persistence in which the lagged dependent variable is an explanatory variable included in the model in order to test the persistence hypothesis. We also control for other factors influencing the decisions to engage in R&D cooperation activities as outlined below.

For the second aim of our empirical research the dependent variable is defined as a categorical variable which takes three values: (1) if the firm undertook R&D cooperation activities during all the period of study (*Persistent co-operator*); (2) if the firm undertook R&D cooperation activities in some periods but not in all of them (*Sporadic co-operator*); and (3) if the firm never cooperated during the whole period (*Recurrent non co-operator*).

Following previous theoretical and empirical works, among the factors leading firms to engage in collaborative innovative activity, in this paper we focus on the roles of *incoming spillovers* and *legal protection*, the firm's absorptive capacity (*R&D intensity*) and the receipt of public funding for innovation (*Local, National and European funding*). We also control for some firm's characteristics such as *firm size, belonging to a group* of enterprises and sectoral dummy variables indicating the sector to which the firm belongs to.

*Incoming spillovers* refer to the flows of external knowledge that a firm is able to capture, and the information sources for them are usually situated in the public domain (Cassiman and Veugelers, 2002). This way, this variable is measured by the importance that the firm attributed, on a four-point scale, to publicly available information for the innovation process of the firm. The information sources were conferences, trade fairs, exhibitions, scientific journals and trade/technical publications, professional and industry associations. To generate a firm-specific measure of incoming spillovers, we aggregated these answers by summing the scores on each of these questions and then the variable was rescaled from 0 (unimportant) to 1 (crucial). Firms that place a higher value on incoming spillovers and externally generated knowledge in their innovative activity might have a greater scope for learning and gaining from knowledge exchange through cooperative agreements. So these firms are expected to be more likely to be actively engaged in cooperative R&D agreement and to do it more persistently.

Likewise, we account for appropriability conditions, which could be an important factor in explaining patterns in cooperation and their persistence as firms can have less incentives to cooperate for anti-competitive reasons or they may have more incentives in order to learning from others while internalizing the knowledge flows shared between partners. In other words, a better appropriability of the results of innovation through protection may have a positive effect on cooperation in R&D, as firms can control outgoing information flows and there are less incentives for others to become a free rider on other firms' investments (Cassiman and Veugelers, 2002). However, excessive legal protection may hinder the internalization of the flows shared by the partners and may thus have a negative effect on R&D cooperation (Hernán et al., 2003; López, 2008). As a proxy for appropriability conditions, we computed the variable *legal protection*, which considers whether the firm used at least one legal method for protecting inventions or innovations (patents, registered an industrial design, trademark or copyright), taking a value of 1 if used, and zero otherwise.

Regarding the receipt of public funding for innovation, when firms obtain public R&D subsidies they may be more likely to establish cooperation agreements with other firms or with institutions given that this way they have the resources to do the research (Arranz and Fdez de Arroyabe, 2008; Busom, Fernández-Ribas, 2008; Abramovsky et al., 2009). Also, many times public support programmes for R&D activities aim to ease cooperative innovation agreements by firms that would otherwise not engage in such activity. In order to distinguish the effect from different sources of public R&D subsidies, we define three binary variables: *local, national and European funding*, taking the value 1 if the firm received public funding from local or regional authorities, central government and European Union, respectively, to carry out its innovation activities, and zero otherwise.

*R&D intensity* as a proxy for absorptive capacity and *firm size* are expected to influence positively cooperation activities. Firms' R&D intensity (measured as the share of internal R&D expenditures in total sales) represents their R&D efforts (experience and knowledge accumulated) and according to Cohen and Levinthal (1989), greater efforts in R&D increase the firm's capacity to recognize, value, and assimilate external knowledge from cooperation agreements. Absorptive capacity has been identified in many studies as an important feature of the firms since it makes them more likely to be successful innovators, which could make them more attractive cooperation partners for other firms (Bayona et al., 2001; Fritsch and

Lukas, 2001; Miotti and Sachwald, 2003; Hernán et al., 2003; Belderbos et al., 2004b; Röller et al., 2007; Arranz and Fdez de Arroyave, 2008). On the order hand, it is argued that large firms have more resources and certain capabilities to be more able to face commitments required for partnerships and to benefit from cooperation agreements and from economies of scale (Bayona, et al., 2001; Fritsch and Lukas, 2001; Tether, 2002; Miotti and Sachwald, 2003; Belderbos et al., 2004b; Belderbos et al., 2011). Firm size is a categorical variable (<50 employees, 50-249, 250-499 and >500) according to the number of employees.

We expect firms *belonging to a group* of enterprises to be more likely to engage in R&D cooperation. Firms that are part of a group may have access to a substantial pool of resources that make them more attractive as cooperation partners (Ahuja, 2000; Miotti and Sachwald, 2003; Belderbos et al., 2011). We define a binary variable taking the value 1 if the firm belongs to a group of companies, and zero otherwise. See Table A1 in the Appendix for a more detailed explanation of the definitions of the variables.

Some descriptive statistics of the variables used in our empirical analysis are shown in Table 3. Although all of them can vary across firms and time we can see that in all cases the variation across firms (between variation) is much higher compared to the time variation (within variation).

[Insert Table 3 around here]

# 4. The persistence of R&D cooperation

## 4.1 Empirical methodology: a dynamic RE probit model

Our main aim is to analyse if there is persistence in the decision to engage in cooperation agreements as a way to carry out innovation activities. To do this, our empirical approach follows the definition of persistence as "state dependence" (Heckman, 1981), which means that having engaged in arrangements of R&D cooperation increases the probability to engage in such arrangements currently. A similar approach has been applied to analyse persistence of innovation activities at the firm level by several studies (Mañez et al., 2009; Peters, 2009; Raymond et al., 2010; Triguero and Córcoles, 2013), but, with the exception of Belderbos (2011), we have not found other works studying persistence in R&D cooperation activities.

As we observed in the transition probabilities presented in the previous section, it seems that such decision is fairly persistent, but this needs to be further tested in a regression model which includes control variables. So, we consider a dynamic random effects probit model which allows for state dependence and unobserved individual heterogeneity. Likewise, in order to distinguish the true state dependence from the spurious one, this dynamic framework accounts for unobserved individual effects correlated with the initial conditions.

The latent equation for this model is specified as:

$$y_{it}^{*} = \gamma\, y_{it-1} + x_{it}^{'}\beta + \alpha_i + \varepsilon_{it} \qquad i = 1, ..., N; t = 2, ..., T \qquad (1)$$

where $y_{it}^{*}$ is the latent dependent variable which measures the difference between benefits and costs that firm *i* obtains during the current period *t* by cooperating in R&D with other firms or institutions; $y_{it-1}$ is an indicator for the cooperation during the previous period; $\gamma$ is the parameter that represents the true state dependence to be estimated; $x_{it}$ is a vector of observable characteristics of the firm that may be associated with the cooperation indicator and $\beta$ the corresponding vector of parameters to be estimated; $\alpha_i$ are unobserved individual-specific random effects which are assumed to be uncorrelated with the independent variables; and $\varepsilon_{it}$ is a time and individual-specific error term that is assumed to be distributed as $N(0,1)$[7]. If $y_{it}^{*}$ is larger than zero we observe that firm *i* engages in cooperation, so the observed binary outcome variable is defined as:

$$y_{it} = \begin{cases} 1 & if\ \ y_{it}^{*} \geq 0 \\ 0 & else \end{cases} \qquad (2)$$

Since $\varepsilon_{it}$ is normally distributed, the dynamic model of interest is given by

$$P\left[y_{it} = 1 | x_{it}, y_{it-1}, \alpha_i\right] = \Phi\,(\gamma\, y_{it-1} + x_{it}^{'}\beta + \alpha_i) \qquad (3)$$

[7] A fixed effects model, in which the individual specific effect ($\alpha_i$) is correlated with the independent variables, suffers from the so-called "incidental parameter problem" making it unfeasible to estimate. For this reason, the literature generally assumes a random effects specification in this kind of analysis. In addition, since we are considering a sample of the whole population of Spanish firms, i.e., a random sample from a large population, the random effects model would be more appropriate based on theoretical grounds (Hsiao, 2004; Baltagi, 2005).

where $\Phi$ is the cumulative distribution function of a standard normal.

Since the variance of the error in the latent variable model is unity, the relative importance of the unobserved effect is measured as $\rho = \sigma_{\alpha}^{2} / (\sigma_{\alpha}^{2} + 1)$. Testing the statistically significance of this coefficient leads to an easy test for the presence of the unobserved effect, that is, the relevance of random effects estimator over the pooled one.

A positive and statistically significant estimate of $\gamma$ identifies the presence of persistence in the decision to engage in cooperation agreements for innovation. As we mentioned in section 2, it may arise due to true state dependence or due to unobserved characteristics of the firms that are correlated over time. As pointed out by Raymond et al. (2010), the existence of true persistence can be ascertained only after accounting for unobserved individual effects and handling properly the initial conditions problem. The simplest assumption is to take the initial conditions ($y_{i1}$) to be exogenous, but it is not expected so because the start of the observation period for each firm could be correlated with the unobserved characteristics of the firms. In our context, if the initial conditions are taken to be exogenous, the coefficient of the lagged dependent variable would be overestimated. In other words, it will lead to an overstatement of the true state dependence in R&D cooperation decisions.

We follow the Wooldridge's (2005) procedure which deals with the initial conditions problem in non-linear dynamic random effects models by assuming that the unobserved individual effects are determined by initial values and the time-varying exogenous variables, namely:

$$\alpha_i = \delta_0 + \delta_1 y_{i1} + \delta_2 \overline{x}_i + u_i \tag{4}$$

where $\overline{x}_i$ represents the means of time-variant exogenous variables; $u_i$ is assumed to be distributed $N(0,1)$ and independent of the explanatory variables, the initial conditions, and the idiosyncratic error term ($\varepsilon_{it}$)[8].

[8] Since the regressors exhibit too little time variation (within variation) and given the high correlation between the variables and their within means (see Table 3 and Table A2 in the Appendix), we are not able to identify $\delta_2$ and hence, we followed the strategy adopted by Raymond et al. (2010) assuming that the unobserved individual effects are correlated only with the initial values of $y_{it}$.

Next section offers our results for two different specifications: first, a random effects dynamic probit where we introduce lagged endogenous variables (the initial conditions are assumed as exogenous) and, second, the alternative specification proposed by Wooldridge (2005) where we account for the initial conditions of the dependent variable and individual-specific effects.

### 4.2 Is R&D cooperation persistent? Main results

The results of the dynamic random effects probit model are shown in Table 4. As it is observed, the statistical significance of the panel-level variance component ($\rho$) in the total variance indicates that the random effects estimator is preferred over the pooled probit estimator, indicating the accuracy of considering the first one. In the first column, we report the marginal effects from the estimation of the dynamic random effects probit model taking into account the unobserved individual heterogeneity and assuming the initial conditions as being exogenous. As mentioned before, since the persistence of engaging in R&D cooperation may be spurious when the individual effects and the initial conditions are not addressed, these results can be contrasted with the estimates obtained assuming that the initial conditions are correlated with the individual effects, as presented in the second column. Also in Table 4, we report the results for the balanced panel in order to obtain an indication of the magnitude of the survivorship bias that may be present when the sample is reduced. By and large, the results of the two datasets are very similar. Therefore, it can be taken as a robustness check confirming our results about the persistence in R&D cooperation activities.

[Insert Table 4 around here]

Our main interest is in the estimated coefficient of the lagged cooperation ($\text{Cooperation}_{t-1}$). As it can be seen, the effect of this variable is positive and highly significant. This result indicates that firms are persistent in carrying out cooperation activities as a strategy to undertake their innovation activities. After taking into account the assumption of the initial conditions correlated with the unobserved individual effects the results remain. However, in line with previous findings in the literature, the hypothesis of exogenous initial conditions leads to overestimation of state persistence. The results show that the coefficient of the state dependence ($\gamma$) is larger in the case of the random effects model with exogenous initial conditions (47.3%) than in the Wooldridge model (33.7%). Hence, after discounting the impact of observed and unobserved firm characteristics, a firm cooperating in t-1 has a probability of cooperating which is approximately 34 percentage points higher than that of a firm not having cooperated in the previous period.

We also find that the importance attributed to public sources of information publicly accessible, the use of protection methods, firm size, and the fact of belonging to a group of enterprises affect positive and significantly the probability to cooperate. Furthermore, it is worth noting that taking into account the dynamic behaviour of cooperation, the firm's decision to cooperate in R&D activities depends significantly on public funding (local, national and European). This result is in accordance with many studies analysing the relationship between R&D cooperation and subsidies (Busom and Fernández-Ribas, 2008; Arranz and Arroyabe, 2008; Abramovsky et al., 2009) and evidence that R&D subsidies designed to encourage innovations activities could alleviate barriers to cooperation. Of course this dependence of R&D cooperation on public funding can be a problem for the long-term R&D strategy of the firm, since not receiving public funds because of cyclical reasons could force the firm stopping their cooperation agreements.

Since we have obtained that there is clear evidence of the existence of persistence in the cooperation due to true state dependence, we are now interested in investigating which are the characteristics of the firms that cooperate in a continuous way compared with those cooperating in a sporadic way. We will do that in the next section.

## 5. Which are the characteristics of firms that cooperate in a continuous way?

### 5.1 Empirical methodology: Multinomial probit estimation

The second purpose of this study is to analyse the factors driving the different cooperation profiles. We distinguish three types of profiles: the recurrent non co-operator, the sporadic co-operator and the persistent co-operator. So, we define a dependent variable that takes three values: (1) if the firm never cooperated during the whole period; (2) if the firm undertook R&D cooperation activities in some periods but not consecutively; (3) if the firm undertook R&D cooperation activities in at least two consecutive waves.

In order to determine the factors that affect the likelihood of undertaking R&D co-operation activities in a continuous or sporadic way, we estimate a multinomial probit model. The main advantage of this model is that it allows us to make comparisons about why some firms cooperate in a sporadic way instead of being a persistent co-operator. Likewise, it helps us to quantify the impact of different characteristics on the probability of a firm being a persistent co-operator or an occasional co-operator relative to not cooperating at all over the period.[9]

The latent equations of the multinomial probit model are

$$y_{ij}^{*} = x_{ij}^{'}\beta_j + u_{ij}, \quad j = 1,2,3, \;\; [u_{i1}, u_{i2}, u_{i3}] \sim N[0, \Sigma] \qquad (5)$$

where, again, $y_{ij}^{*}$ represent the latent variables that reflect an underlying benefit – cost calculation of cooperation in a continuous, sporadic way or lack of cooperation of firm *i*; the firms' observable characteristics and sector variables are given by *x*; $\beta_j$ are a set of parameter matrices to be estimated for each cooperation profile *j*; and *u* is a component of the error which has a multivariate normal distribution with mean zero and covariance matrix $\Sigma$. Since we do not observe the latent variables $y_{ij}^{*}$, but we do observe the type of co-operator the firm is (non co-operator, *y*=1; sporadic, *y*=2; or persistent, *y*=3), formally the probability of being a non co-operator is

$$\begin{aligned} \text{Prob}[y_i = 1] &= \text{Prob}[y_{i1}^{*} > y_{i2}^{*} \text{ and } y_{i1}^{*} > y_{i3}^{*}] \\ &= \text{Prob}[u_{i2} - u_{i1} > (x_1 - x_2)'\beta, u_{i3} - u_{i1} > (x_1 - x_3)'\beta] \end{aligned} \qquad (6)$$

Similar expressions are calculated for being a sporadic and a persistent co-operator.

### 5.2 Determinants of the different profiles of R&D cooperation

Table 5 presents the marginal effects from the estimation of the multinomial probit model for the exclusive categories of cooperation profiles, which are calculated at the mean marginal effect over all observations[10].

[9] The multinomial probit model is an alternative modeling method that relaxes the Independence of Irrelevant Alternatives (IIA) assumption of the multinomial logit model. A more detailed explanation of these models can be found in Maddala (1983), Amemiya (1985), Greene (2008) and Wooldridge (2002). In any case, we also made the regressions using the multinomial logit model and the results were similar. They can be provided by the authors upon request.

[10] Based on the corresponding likelihood ratio test we obtained a test statistic of 5908.4 which is above the critical value of the chi-square with 4 degree of freedom, indicating the superiority of the multinomial probit model to the estimation of separated univariate probit models.

The results show that there is a relevant relationship between public funding for innovation and the cooperation profile, especially funds coming from the European Union, which presents the highest marginal effect. Interestingly, the effect of public R&D subsidies on firm's likelihood of being persistent co-operator is strongly positive but it is negative in the case of sporadic and non-cooperator. For instance, the probability of engaging in R&D cooperation activities continuously is around 16 percentage points higher among firms that receive public funding from European Union compared to non-receivers of such funding, while firms receiving such funding are 4.6 percentage points less likely to cooperate in a sporadic way. This result is consistent with those findings found in the first analysis supporting the idea that R&D subsidies can encourage cooperative relationships between firms and institutions over time.

Other variables positive affecting the probability of being a firm cooperating continuously are the importance attributed to public sources of information (Incoming spillovers) and legal protection. In line with other empirical works, we find that firms attributing high importance to publicly available information sources for innovation are more likely to engage in R&D cooperation agreements (Cassiman and Veugelers, 2002; López, 2008), but our results highlight that it does not only play an important role for the existence of R&D cooperation as many studies are confirmed but it is also a determinant of its persistence. A higher importance given to publicly available information increases the probability of being persistent co-operator by approximately 11 percentage points. On the other hand, the use of legal protection methods like patent, trademark or copyright have a positive and significant effect on the probability of being a persistent co-operator but it has a negative impact on the propensity to cooperate in an occasional way. Hence, high appropriability (low level of outgoing spillovers) influence positively firm's decision to cooperate persistently in order to carry out their innovation activities.

Regarding R&D intensity, the results show that the higher internal R&D intensity, the higher likelihood of cooperation persistence. This positive result is consistent with the literature highlighting the fact that a higher absorptive capacity of a firm may allow it to derive greater benefits from cooperation with other partners (Cohen and Levinthal, 1989). However, no evidence was found for the sporadic alternative. As far as firm size is concerned, we can see that it has also a strong and positive effect on persistence. Large firms are more likely to engage in R&D cooperation persistently than small firms. In contrast, there are no relevant effects of size on probability of being a sporadic co-operator.

Finally, firms that belong to a group of enterprises are most likely to engage in R&D cooperation agreements persistently not only because this factor affects positively the persistence, but it also affects negatively the probability of being sporadic co-operator and non-cooperator. This is consistent with the idea that this kind of firms has probably easier access to financial and technological resources that are available in their group making them more attractive as cooperation partners.

[Insert Table 5 around here]

## 6. Conclusions

This study provides evidence on the persistence of engaging in cooperation activities in Spanish firms using the PITEC (Panel de Innovación Tecnológica) and on the factors determining the participation of firms in cooperation for innovation activities in a continuous way. The availability of longitudinal firm-level panel data allows us to consider the dynamics in a firm's behaviour of engaging in R&D cooperation activities.

First, we estimate a dynamic random effects probit model in order to test the hypothesis on the existence of persistence of R&D cooperation at the firm level. We try to identify the true state dependence which differs from the spurious state dependence state (see Heckman, 1981) taking into account the individual effects and handling the initial conditions problem present in this kind of analysis. Persistence or true state dependence takes place when a firm that has engaged in R&D cooperation activities in one period engages in R&D cooperation agreements in the subsequent period. The results show that there is a high persistence in R&D cooperation activities at the firm level and it remains so after taking into account both the individual effects and the initial conditions problem. This result could be explained by the knowledge accumulation and capabilities that may be gained from past experiences in cooperation projects, the barriers to enter and exit which can arise due to sunk costs, and the success and reliability in past cooperation agreements.

Once we identified the existence of persistence in R&D cooperation, we are interested in quantifying and comparing the impact of various firm's characteristics on the probability of being an occasional cooperator or a persistent cooperator relative to not cooperating at all over the period. With this aim, we extended our empirical analysis by estimating a multinomial probit model. The results highlight the important role of the European innovation policy as well as innovation support from the national and regional authorities as a mechanism to promote R&D cooperation strategies. In addition, our findings suggest that the importance attributed to publicly available information sources, the use of protection methods and firm size are strongly driving R&D cooperation activities.

In general terms, our results suggest that there is a kind of firms that cooperate in a continuous way, that is, firms with higher incoming spillovers, higher R&D intensity, large firms and firms that belong to a group of enterprises as well as firms that use protection methods such as patenting, registered an industrial design, trademark or copyright. These features of the firms may make them more likely to be successful innovators, which could make them more attractive cooperation partners for other firms and they probably are more able to face commitments required for partnerships and to benefit from cooperation agreements.

In addition, from a policy view, our results suggest that since R&D cooperation is state dependence, promoting policies to encourage cooperation as a strategy to carry out innovation activities such as government financial support would have a much wider impact because they do not only affect current collaboration agreements but are also likely to prompt a permanent change in favour of R&D cooperation.

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## Tables

**Table 1. Characteristics of the panel data sets used**

| | Unbalanced panel | Balanced panel |
|---|---|---|
| Number of observations | 25,364 | 16,016 |
| Number of firms | 7,566 | 4,004 |
| Number of consecutive obs. per firm | >=2 | 4 |
| Average number of consecutive obs. | 3.4 | 4 |

**Table 2. Transition probabilities matrix**

| | | Cooperation in t | | | |
|---|---|---|---|---|---|
| | | Unbalanced panel | | Balanced panel | |
| Cooperation in | | Non-cooperation | Cooperation | Non-cooperation | Cooperation |
| t-1 | Non-cooperation | 83.70 | 16.30 | 82.50 | 17.50 |
| | Cooperation | 29.24 | **70.76** | 27.39 | **72.61** |
| t-2 | Non-cooperation | 78.22 | 21.78 | 77.63 | 22.37 |
| | Cooperation | 39.01 | **60.99** | 36.99 | **63.01** |
| t-3 | Non-cooperation | 73.35 | 26.65 | 73.35 | 26.65 |
| | Cooperation | 43.43 | **56.57** | 42.89 | **57.11** |

**Table 3. Descriptive statistics of variables in the empirical analysis**

| | Unbalanced | | | | Balanced | | | |
|---|---|---|---|---|---|---|---|---|
| | mean | std. dev. | | | mean | std. dev. | | |
| | | overall | between | within | | overall | between | within |
| Cooperation_t-1 | 0.382 | 0.486 | 0.414 | 0.268 | 0.409 | 0.492 | 0.395 | 0.293 |
| Incoming spillovers | 0.363 | 0.277 | 0.240 | 0.151 | 0.380 | 0.275 | 0.223 | 0.161 |
| Legal protection | 0.357 | 0.479 | 0.408 | 0.266 | 0.377 | 0.485 | 0.387 | 0.291 |
| R&D intensity | 0.075 | 0.245 | 0.240 | 0.083 | 0.071 | 0.233 | 0.216 | 0.086 |
| Firm size | 314.244 | 1430.165 | 1440.760 | 280.152 | 334.356 | 1305.782 | 1277.710 | 269.809 |
| Local funding | 0.300 | 0.458 | 0.390 | 0.252 | 0.321 | 0.467 | 0.379 | 0.273 |
| National funding | 0.269 | 0.444 | 0.370 | 0.250 | 0.296 | 0.456 | 0.366 | 0.273 |
| European funding | 0.074 | 0.261 | 0.220 | 0.139 | 0.083 | 0.276 | 0.228 | 0.155 |
| Belonging to a group | 0.416 | 0.493 | 0.472 | 0.147 | 0.442 | 0.497 | 0.470 | 0.160 |

**Table 4. Marginal effects from dynamic random effects probit**

| | Unbalanced panel | | Balanced panel | |
|---|---|---|---|---|
| | Random effects probit | Wooldridge correction | Random effects probit | Wooldridge correction |
| Cooperation $_{i,t-1}$ (*persistence*) | 0.473*** | 0.337*** | 0.470*** | 0.329*** |
| | (0.008) | (0.018) | (0.011) | (0.020) |
| Cooperation $_{i,t1}$ (*initial conditions*) | | 0.188*** | | 0.204*** |
| | | (0.021) | | (0.024) |
| Incoming spillovers | 0.095*** | 0.106*** | 0.090*** | 0.099*** |
| | (0.016) | (0.018) | (0.020) | (0.024) |
| Legal protection | 0.035*** | 0.040*** | 0.036*** | 0.041*** |
| | (0.009) | (0.010) | (0.011) | (0.013) |
| R&D intensity | 0.088*** | 0.107*** | 0.096*** | 0.123*** |
| | (0.024) | (0.028) | (0.035) | (0.042) |
| *Firm size (base <50 employees)* | | | | |
| 50 – 249 emp | 0.039*** | 0.046*** | 0.038*** | 0.047*** |
| | (0.010) | (0.012) | (0.013) | (0.016) |
| 250 – 499 emp | 0.056*** | 0.067*** | 0.056*** | 0.070*** |
| | (0.016) | (0.020) | (0.020) | (0.025) |
| 500 or more emp | 0.102*** | 0.119*** | 0.097*** | 0.115*** |
| | (0.018) | (0.022) | (0.023) | (0.028) |
| *Public funding for innovation* | | | | |
| Local funding | 0.096*** | 0.099*** | 0.103*** | 0.103*** |
| | (0.010) | (0.011) | (0.013) | (0.015) |
| National funding | 0.099*** | 0.104*** | 0.098*** | 0.101*** |
| | (0.011) | (0.012) | (0.013) | (0.015) |
| European funding | 0.119*** | 0.124*** | 0.133*** | 0.134*** |
| | (0.019) | (0.022) | (0.023) | (0.027) |
| Belonging to a group | 0.062*** | 0.071*** | 0.077*** | 0.091*** |
| | (0.010) | (0.012) | (0.013) | (0.015) |
| Industry dummies | Included | Included | Included | Included |
| Time dummies | Included | Included | Included | Included |
| Observations | 17,568 | 17,568 | 12,012 | 12,012 |
| Number of firms | 7,566 | 7,566 | 4,004 | 4,004 |
| Log L | -8418.381 | -8370.928 | -5852.373 | -5809.207 |
| Wald test ($\chi^2$) | 5007.341 | 3605.362 | 3256.116 | 2339.050 |
| | Pval = 0.000 | Pval = 0.000 | Pval = 0.000 | Pval = 0.000 |
| Rho ($\rho$) | 0.049 | 0.288 | 0.080 | 0.320 |
| Likelihood test ($H_0$: $\rho=0$) | 4.375 | 78.444 | 7.681 | 77.860 |
| | Pval = 0.018 | Pval = 0.000 | Pval = 0.003 | Pval = 0.000 |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

**Table 5. Marginal effects from multinomial probit model**

| | Non co-operator | Sporadic | Persistent |
|---|---|---|---|
| Incoming spillovers | -0.060*** | -0.047** | 0.107*** |
| | (0.014) | (0.019) | (0.023) |
| Legal protection | -0.010* | -0.027** | 0.037*** |
| | (0.006) | (0.011) | (0.012) |
| R&D intensity | -0.040** | -0.043 | 0.082*** |
| | (0.018) | (0.027) | (0.032) |
| *Firm size (base <50 employees)* | | | |
| 50 – 249 emp | -0.022*** | -0.002 | 0.024* |
| | (0.007) | (0.012) | (0.015) |
| 250 – 499 emp | -0.040*** | -0.014 | 0.054*** |
| | (0.010) | (0.017) | (0.020) |
| 500 or more emp | -0.054*** | -0.029* | 0.083*** |
| | (0.011) | (0.017) | (0.020) |
| *Public funding for innovation* | | | |
| Local funding | -0.080*** | -0.060*** | 0.141*** |
| | (0.013) | (0.014) | (0.017) |
| National funding | -0.053*** | -0.036*** | 0.089*** |
| | (0.011) | (0.013) | (0.016) |
| European funding | -0.115*** | -0.046** | 0.162*** |
| | (0.015) | (0.019) | (0.022) |
| Belonging to a group | -0.033*** | -0.058*** | 0.091*** |
| | (0.007) | (0.012) | (0.014) |
| Industry dummies | | Included | |
| N | | 4004 | |
| Log L | | -3903.45 | |

Standard errors in parentheses *** p<0.01, ** p<0.05, * p<0.1

## Appendix

**Table A1. Definition of the variables included in the empirical analysis**

| Variables | Definitions |
|---|---|
| **Dependent** | |
| Cooperation $_t$ | = 1 if the firm cooperated in some of its innovation activities with other enterprises or institutions in the period t<br>= 0 otherwise |
| *Cooperation profile:* | |
| Persistent co-operator | = 1 if the firm cooperated in some of its innovation activities during at least two consecutive waves |
| Sporadic co-operator | = 2 if the firm cooperated in some of its innovation activities in some periods but not consecutively |
| Recurrent non co-operator | = 3 if the firm never cooperated in some of its innovation activities during all the period of study |
| **Independent** | |
| Cooperation $_{t-1}$ | = 1 if the firm cooperated in some of its innovation activities with other enterprises or institutions in the period t-1<br>= 0 otherwise |
| Incoming spillovers | = 1 if firm gives high importance to the following information sources for undertaking its innovation activities: conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations.<br>= 0 otherwise |
| Legal Protection | = 1 if the firm uses at least one of the following legal methods for protecting inventions or innovations: applied for a patent; registered an industrial design; registered a trademark; claimed copyright<br>= 0 otherwise |
| R&D Intensity | Ratio between intramural R&D expenditure and turnover |
| Firm Size | <50 employees =1 if the firm has less than 50 employees; =0 otherwise<br>50 – 249 employees =1 if the firm has between 50 and 249 employees; =0 otherwise<br>250 – 499 employees =1 if the firm has between 250 and 499 employees; =0 otherwise<br>500 or more employees =1 if the firm has 500 or more employees; =0 otherwise |
| Local funding | = 1 if the firm receives funding from local or regional authorities to carry out its innovation activities<br>= 0 otherwise |
| National funding | = 1 if the firm receives funding from central government to carry out its innovation activities<br>= 0 otherwise |
| European funding | = 1 if the firm receives funding from European Union to carry out its innovation activities<br>= 0 otherwise |
| Belonging to a group | = 1 if the firm belongs to a group of enterprises<br>= 0 otherwise |

All explanatory variables are taken from t-1 period.

**Table A2. Correlation between the explanatory variables and their corresponding within means**

| | |
|---|---|
| Incoming spillovers | 0.839 |
| Legal protection | 0.832 |
| R&D intensity | 0.941 |
| Firm size | 0.981 |
| Local funding | 0.836 |
| National funding | 0.826 |
| European funding | 0.846 |
| Belonging to a group | 0.954 |