Dynamics and Interrelation of R&D Collaboration and Innovative Performance

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Abstract

We investigate the two-way interrelationship between firm innovative performance and collaborative R&D with different partners (suppliers, clients, competitors and research institutions & universities), taking into account dynamic patterns of R&D collaboration. In a large panel of Spanish innovating firms, we find support for the proposition that it is continuous R&D collaboration rather than new or interrupted collaboration that enhances innovative performance. Strong prior innovative performance increases the probability of the formation of new collaborative ties, with the exception of collaboration with competitors, consistent with the notion that successful firms fear leakage of proprietary knowledge to rivals. Existing collaboration with one partner increases the likelihood of R&D collaboration with other types of partners, with the strongest effects evident for collaboration with research institutions & universities.

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1. INTRODUCTION

An expanding literature has examined the firm-level determinants and drivers of R&D collaboration (e.g. Arranz and Arroyabe, 2010; Belderbos et al, 2004a; Ahuja, 2000a; Tether, 2002; Tether and Tajar, 2008; Mitchell and Singh, 1992; Belderbos et al., 2012; Sanchez-Gonzales et. al, 2009) and the performance consequences of such collaboration (e.g. Baba et al., 2009; Un et al, 2008; Lhuillery and Pfister, 2009; Chung and Kim, 2003; Duysters and Lokshin, 2011). Extant research making use of information drawn from Community Innovation Surveys has suggested that differentiating between types of collaboration partners is important both for the antecedents and the consequences of R&D collaboration, and has distinguished between suppliers, customers, competitors, and universities or research institutes as partners (e.g. Belderbos et al, 2004b; 2006; Un et al, 2008).

As broad as the literature has become, at least three issues have not received due attention. First, the determinants or consequences have been examined in isolation, without much regard to the notion that there is a possible feedback effects from performance to the need or opportunities to engage in subsequent R&D collaboration (Ahuja, 2000b). Second, most studies have examined the consequences and determinants of engagement in R&D collaboration at a point in time, ignoring different dynamic patterns of R&D collaboration related to the startup of collaboration, and their duration and interruption. Third, the dynamic relationship between the different types of collaboration, i.e. the extent to which prior engagement in one type of collaboration suggests the formation of new collaborative ties with other partners, has not been investigated. This is a potential important issue, as different types of collaboration may have a preferential time sequence and because firms may see benefits of a gradual buildup of a portfolio of collaborative strategies (e.g. Belderbos et al., 2012).

The aim of the current paper is to fill these gaps in the extant literature. We examine both the determinants and performance consequences of different types of R&D collaboration. Specifically, we argue that prior innovative performance will have a differential impact on the propensity to forge new collaborative ties depending on the collaboration partner. In contrast to most prior work, we examine the dynamics of collaborative formation, by analyzing the propensity to set up new collaborations (rather than analyzing the propensity to be engaged in collaboration per se), and by distinguishing new collaborations from continuous collaboration, and interrupted collaboration with different types of partners. Finally we uncover specific patterns of intertemporal relationships between collaboration with different types of partners, suggesting particularly strong relationships between the two vertical chain partners (customers and suppliers), and between institutional collaboration and other collaboration types.

Based on a review of the literature we distill a number of propositions which guide our empirical research and interpretation. Empirically, we draw on panel data on a large sample of Spanish innovating firms reporting on innovation activities on a yearly basis. We posit a recursive model of interrelation between innovative performance and R&D collaboration. We estimate a dynamic performance equation as well as a multivariate probit model of the formation of new R&D collaborative ties with the four different partner types. We define innovative performance in productivity terms as sales of new to the market products and services per employee.

The remainder of this paper is organized as follows. In the next section we review the literature and derive our propositions. Section 3 describes the data, variables and empirical methods. Section 4 discusses the empirical results and section 5 concludes.

2. LITERATURE AND PROPOSITIONS

We review the extant literature on the relationship between R&D collaboration and firm performance. We structure the review by focusing first on the evidence on the performance consequences of (different types of) R&D collaboration, followed by insights on interrelation between the different types of collaboration, and the feedback effect of innovative performance on the incentives and opportunities to collaborate subsequently. Based on the review we derive a number of propositions that guide and help interpret the empirical analysis.

2.1 Cooperation types and firm innovative performance

Internal sources of technological development are often inadequate to cope with the complexity and uncertainty of current technology development processes. To stay competitive, firms increasingly rely on external sources of knowledge, which may account for between 34% and 65% of the inputs important for development of successful innovations (Conway, 1995). Technological cooperation constitutes a prime vehicle in this knowledge-sourcing process. In this section we review a number of channels through which firm's technology cooperation activities can impact innovation, by highlighting the role each type of partner plays in this process. We also discuss the differential impact of new, continuous and discontinued technology cooperation on firm's innovative performance.

Cooperation with *universities* and *public research institutions* has been found an important source of new scientific and technological knowledge. Such collaboration can for instance, lead to development of new (radical) applications of already existing technology (Archibugi and Coco, 2004; Drejer and Jorgensen, 2005; Arvanitis et al., 2008). Engaging in university collaboration can be attractive for industry partners since it allows inexpensive and

low-risk access to specialist knowledge and generic, basic R&D (Aronson et al., 2001; Arranz and Arroyabe, 2008; Beers et al., 2008; Mototashi, 2008). Academic research, carried out by the universities and public research organizations, has been shown to be complementary to firm's own innovation activities, thus significantly contributing to firm's ability to create innovations (Tether and Tajar, 2008; Baba et al., 2009). There are estimates that as much as 15% of new products would not have been developed by firms in the absence of recent academic research (Mansfield, 1998). Jiang et al. (2010) find that in early stages of the industry life cycle, the exploration of scientific knowledge in the public domain is instrumental in achieving innovation success. Thursby and Thursby (2006) also emphasize the importance of university collaboration in achieving key innovations. Cooperation with universities and research institutes also implies connection into international knowledge networks (Okubo and Sjöberg, 2000). Access to this research through engaging in collaboration with universities is thus an integral part of firm's innovation strategies.

Cooperation with *customers* can be instrumental in reducing the risks associated with market introduction of new products, in particular when the new products require adaptations in use due to their complexity or novelty (Tether, 2002; Von Hippel, 1988). By better connecting with the customer firms harness such collaboration to increase the attractiveness of the products and to extend the product or process life cycle (Herstatt and von Hippel, 1992; Jeppsen and Molin, 2003). Cooperation with customers has been found particularly important in the presence of heterogeneous needs in the market and when information on customer needs and technology is sticky (Sanchez-Gonzales et al., 2009; von Hippel and Katz, 2002). Furthermore, companies that continuously collaborate with customers may develop new competences that are required for the realization of shorter lead times, improved quality, and greater flexibility, resulting in improved efficiency, innovativeness and market responsiveness (Choi and Hartely, 1996; Childerhouse et al., 2002).

Cooperation with *suppliers* can increase the knowledge over the cost-reducing technologies, improve the firm's focus on core competences, improve design processes, and secure vital inputs (Suzuki, 1993; Kamath and Liker, 1994). The resource based view of technology collaboration suggests that alliances with suppliers can provide a focal firm with the opportunity to steer its supplier's development efforts and thus influence its competences (e.g. Ragatz et al., 1997). The effective integration of suppliers into new product development can help firms achieve advantage over competitors in terms of the cost of new product development, utilized technologies and development time. Eisenhardt and Tabrizi (1994) find that supplier involvement can increase product innovation in mature industry segments while Saeed et al. (2005) argue that it can help firms realize higher process efficiencies. Chung and Kim (2003) find that collaboration with suppliers may reduce risk and lead times of product development. The importance of cooperation with suppliers and customers for product development is also stressed by Nieto and Santamaria (2007).

Cooperation with *competitors* tend to focus on research trajectories that precede application in the competitive markets (Baum and Ingram, 2002). Typically, research consortia fall into this category where competitors work together in order to share the costs and risks of research, pool scare expertise and equipment and aim to develop far-from-market technology with generic application potential (Miotti and Sachwald, 2003; Tidd et al., 2005). Firms may seek cooperation with competitors in case they face common problems (Gnyawali and Park, 2011). Although the realization of a completely new technology may require a long time horizon, firms can reap direct benefits from the collaboration by learning about their competitors' specific fields of expertise. Since this is a two-way process, a degree of trust between firms is needed to make the collaboration a success (Nooteboom, 2004). In this way, earlier collaboration with competitors may signal that a company is not only a competent partner that disposes over scarce expertise but is also a trustworthy one, thus increasing

potential collaboration with other types of partners (Duysters and Lemmens, 2003). Following a resource-based view, pre-competitive collaboration with competitors may create access to scarce, external expertise on promising new technologies (Hagedoorn, 2002). Moreover, horizontal collaboration allows firms to combine and integrate complementary knowledge and capabilities from a diversity of actors (Smith Ring and Van de Ven, 1994; Ahuja, 2000; Rowley et al., 2000), yielding a potential for the generation of technology with a large novelty value (Gilsing et al., 2008).

The effect of cooperation has an important temporal element. A recently started cooperation may not yet result in innovation outcomes. It may take a couple of months to a couple of years before the fruits of the venture may be reaped. If successful, (the type of) cooperation is likely to be continued. Cooperation strategies can also be expected to be persistent, due to habitual forces and path dependence. Organizations tend to establish routines that are associated with satisfactory performance, which are then replicated and perpetuated, leading to path-dependency in their behavior and strategy (Nelson and Winter, 1982; Levitt and March, 1988; Li and Rowley, 2002). Firms that continuously cooperate with a particular type of partner are particularly well-placed to reap the benefits from inter-firm partnering, since these firms are likely to have refined the organizational routines for cooperation and increased experience in managing inter-firm relationships (Das and Teng, 2000, Powell et al., 1996). Furthermore, research has shown that learning takes place through repeated cooperation (e.g. Reuer et al., 2002). The learning effect achieved through engaging continuously in cooperation can in its turn increase the efficiency of partnering strategies (Faems et al., 2005).

To summarize, we expect a positive impact of new as well as continuous cooperation on firm's innovation performance. The impact of continuous cooperation is expected to be larger since firms that have been cooperating for extended period of time have established necessary

routines and gained experience managing cooperation and are therefore more efficient in partnering strategies.

Despite the apparent benefits for firm performance, failure is a frequent outcome of inter-firm partnering. Unsuccessful cooperation rates of 30-50% are no uncommon findings in the literature (e.g. Bleeke and Ernst, 1991; Harrigan, 1988; Killing, 1988). Especially collaboration with competitors and with public research organizations has been found to be more likely to introduce delays or failures in innovation projects than cooperation with vertical partners (Lhuillery and Pfister, 2009). When cooperation is crucial to a firm, partnership mal-functioning has been shown to be harmful for its ability to bring innovations into the market (Lokshin et al., 2011). Discontinued cooperation, which is one outcome of partnership malfunctioning, can therefore be expected to have negative consequences for the innovation processes of the firm as it will delay or complicate the acquisition of knowledge necessary for the continuation of firm's innovation cycle. Hence, we expect that discontinued cooperation will be non-positively related to future innovation performance.

Proposition 1: Continuous and new cooperation have a positive effect on innovative performance with the former effect being stronger. Discontinued cooperation has a negative effect on innovative performance.

2.2 Interrelation between different types of cooperation

To deal effectively with the environmental complexity and speed of technological change, companies progressively increase the number of external relationships and external knowledge sourcing strategies (Hoffmann, 2007; Wassmer 2008). A number of recent empirical studies has tried to parse out the determinants and performance consequences of cooperation with different types of partners (Aschhoff and Schmidt, 2008; Belderbos et al.,

2004a,b; Cassiman and Veugelers, 2002; Fritsch and Lucas, 2001; Segara-Blasco and Arauzo-Carod; 2008; Thomlinson, 2010). Most of this literature abstracted, however, from the possibility of inter-relatedness between different types of cooperation.

There are a number of reasons why different types of cooperation may be inter-temporally related, i.e. cooperation with one type of partner increases the likelihood of cooperation with other types. Past technology alliances with suppliers, for instance, not only increase the probability that a firm will cooperate with other suppliers, but may also have an impact on the propensity to engage in new alliances with customers, and vice versa. From the resource-based perspective, this can be understood by the shared need for a systemic coordination across different supply chain activities that typically underlies vertical collaborative processes (Tidd et al., 2005). Coordinating activities throughout the supply chain requires a clear and efficient division of labor between the types of partners in order to be able to rapidly and reliably improve existing products and processes or to reduce operational inefficiencies in the supply chain, such as for example those resulting from 'bullwhip' effects due to demand variability (Metters, 1997; Lee et al, 1997; Gulati and Sytch, 2007). Contributions to the operations management literature have argued that firms spanning the entire vertical value chain including linkages to both customers and suppliers can achieve superior performance (e.g., Narasimhan and Jayaram, 1998; Vickery et al., 2003; Frohlich and Westbrook, 2001; Rosenzweig, Roth & Dean, 2003).

To summarize, there are important drivers to cooperate across the value chain by combining supplier and customer collaboration. Hence, if a firm has been engaged in technology alliances with one of these chain partners, there are strong reasons for it to engage in future collaboration with the other vertical chain partner.

Proposition 2: Cooperation with customers is likely to lead to subsequent cooperation with suppliers and vice versa.

(Pre)-competitive cooperation with competitors is often geared towards (radically) new technology that can help secure future revenue streams. To achieve this, its successful commercialization is required. Vertical collaboration with suppliers and/or customers are better suited for that purpose, given the potential for developing shared capabilities in the field of shortening lead times, increasing flexibility and market responsiveness, and improving efficiency (Rosenzweig et al., 2003; Tidd et al., 2005). Similarly, firms with existing vertical alliances may find more opportunities to introduce efficiently and effectively commercialize the more radical innovations that horizontal alliances aim at. Hence, the resource-based perspective suggests a complementary relationship between horizontal and vertical types of cooperation. Thus, we expect that past horizontal cooperation can lead to (new) cooperation with vertical partners, and the other way around.

***Proposition 3*:** Cooperation with competitors is likely to induce subsequent cooperation with customers and suppliers, and vice versa.

Cooperation with research institutes and universities can be considered as ´generic´. Firms can seek to combine generic with more applied innovation. Recent work on industry-science collaboration has shown that between 10% and 15% of innovative EU and US firms have partnerships with universities and public research organizations (Eurostat). Cooperation with universities and research institutes is generally more aimed at innovations that may open up entire new markets and market segments (Tether, 2002; Monjon and Welbroeck, 2003). Prior research has shown that scientific institutions form a more important source of information

for innovations in science-based technology fields where new break-through innovations can be translated into new products and processes (e.g. Klevorick et al., 1995; Leiponen, 2001; Veugelers and Cassiman, 2005). The nature of knowledge offered by universities means that firms are most likely to establish partnerships with scientific institutions to collaborate on innovation activities that take place in the early stages of the innovation cycle (Thursby and Thursby, 2006). While collaboration with scientific institutions, which is more generic nature, is geared towards development of firm's basic R&D capability, customer/supplier cooperation is geared towards applied R&D activities. To the extent that applied- and basic-R&D capabilities are mutually reinforcing, we would expect that alliances with scientific institutions will increase the marginal benefit and hence propensity of future alliance formation with the industry partners. Hence, we expect that cooperation with institutes is will be combined with cooperation with industry partners.

***Proposition 4*:** Cooperation with research institutes and universities leads to cooperation with other types of partners to reap the fruits of applied innovation.

Firms that continuously engage in collaboration have built a strong reputation of being a reliable and attractive partner, are deeper embedded in a collaborative network and will be better able to generate value from partnerships and consequently will increase opportunities to collaborate with other actors.

Proposition 5: Continuous collaboration with a type of partner, rather than new or interrputed cooperation, has the most notable effect on new cooperation with other types of partners.

2.3 Past innovative success and propensity to cooperate

While technology collaboration is often crucial for innovation success (Hagedoorn 1993; 2002; Duysters and Lokshin, 2011; Rowley et al., 2000; Un et al., 2008), innovation success in turn may spur further collaboration. Firms that established themselves as innovative in the past are considered technologically capable (Stuart et al., 1999) and are therefore desirable as collaborating partner. Ahuja (2000a) showed that propensity to form partnerships is determined by both 'inducements' and 'opportunities', while differences in firm-specific inducements and opportunities largely account for the uneven participation in inter-firm collaborations. Rapidly-innovating firms may have greater 'opportunities' to engage in technological collaboration and are more attractive partners for joint technology development (Ahuja, 2000a). On the other hand, by participating in inter-firm collaboration arrangements, the more successful innovative firms face a danger of involuntary dissipation of their knowledge to potential competitors, which can lead to weakening of their competitive advantage (Mitchell and Singh, 1992). Well-endowed firms are likely to benefit proportionately less from cooperation, relative to their potential partners (Khanna et al., 1998). Hence, high levels of combined technical and commercial expertise importantly reduce the 'inducement' to engage in collaboration (Ahuja, 2000a) and this can outweigh the greater 'opportunities' to form alliances. The stakes of unequal advantage of alliances and knowledge dissipation are greatest for horizontal alliance formation, where competitors benefitting from the technological resources of the firm may threaten the firm directly in its core markets.

A governance perspective similarly points at a risk of knowledge dissipation that is greatest if the alliance is with direct competitors. The probability of opportunistic behavior by one of the partners in the alliance is reduced through mutual dependence (Gulati and Stych, 2007), and the expectation of durability provides the confidence that investments in the alliance can indeed be recouped (Nooteboom, 2004). This mutual dependency is strongest in vertical alliances and weakest in horizontal alliances. In horizontal alliances, the focus is

typically on precompetitive collaboration and aims to generate new, state-of-the-art technology. Firms collaborate in the development of technology but subsequently compete head-on when it comes to commercialization. Hence, the degree of mutual dependency is often not long term and may disappear after specific investments have been recouped. Horizontal alliances also carry a larger risk of knowledge spillovers due to opportunistic behavior as the stakes are higher. Partners may be eager to ally with the highly innovative firm because they see a potential to learn disproportionately more from the collaboration (Ahuja, 2000a). This increases the risk that partners engage in freeriding and take away 'all of the pie' in the later stage of commercialization. In contrast, in vertical alliances the focus of the collaboration is on later phases of commercialization (product innovations) or implementation (process innovations), and partners benefit most if they continue in the development of capabilities rapidly and cost-effectively. Firms with a strong innovation record may also still need to engage in vertical collaboration if the commitment and input of upstream and/or downstream partners is required to sustain its lead (Tidd et al., 2005; Gulati and Sytch, 2007). The above arguments suggest the followin proposition:

Proposition 6: Past innovative performance has a positive effect on the formation of new cooperation ties, with the exception of cooperation with competitors.

3. DATA AND METHOD

3.1 Sample and descriptive statistics

The empirical analysis uses data from the Spanish Survey of Technological Innovation PITEC (Panel de Innovación Tecnológica). The survey is carried out by the Spanish National Statistics Institute (INE), the Spanish Foundation for Science and Technology (FECYT) and the Foundation for Technological Innovation (COTEC). The annual data, from 2004 until

2008 were collected at the establishment level and contain information on firms' innovation activities. The survey covers firms operating in all sectors of the Spanish economy according to the CNAE-93 classification. The PITEC questionnaire, similarly to the Community Innovation Survey, has a multi-layer structure. Only those firms that report to be engaged in innovative activities (e.g. introducing new products, and/or new processes and/or organizational innovations) are asked to complete the entire questionnaire and are the focus of our analysis. Moreover, we eliminated from the sample public firms, research associations and firms from the following sectors: agriculture, extractive firms, oil refineries, production and distribution of electricity, gas and water. Due to missing data on some of the variables we end up with an estimation sample of 8141 firms (19100 observations), from which more than 10% (2079 observations) have at least one cooperative agreement. Our analysis of how past cooperation affects propensity to form new cooperation is based on the estimation sample of 7721 firms (18052 observations). This sample is somewhat smaller compared to the performance model because innovative performance is not always available.

We now discuss the occurrence of new, continuous and interrupted cooperation of the four types. Most firms begin, continue or discontinue cooperation with suppliers and universities/research institutes. These are the most common types of partners. On the other hand, firms engage in cooperation with customers and competitors less frequently. Continuous cooperation is most frequently undertaken with suppliers (828) and institutions (861), followed by clients (162) and competitors (132). Among these firms that already cooperate some embark on new cooperation with other types of partners. Firms with continuous cooperation with universities/research institutions are also responsible for a good share of new research-oriented relationships with suppliers (46), and vice versa (31). Relatively many new cooperative arrangements with clients and with competitors are started by firms that already have partners in suppliers or universities/research institutions. Firms

with continuous cooperation with competitors are a special case. They are the lowest in number (132) and in the original sample there was but one firm with continuous cooperation with competitors that had new cooperation with suppliers, three with new cooperation with clients and four with new cooperation with institutions. We decided to eliminate these observations because there were too few cases to achieve reliable estimates.

The majority of firms discontinued cooperation with suppliers and universities/ research institutes, which are also the most common types of partners. There are 490 firms that discontinued cooperation with suppliers of which 78 started a new agreement with suppliers in the next year, 16 with clients, 13 with competitors and 39 with research institutions. There are 110 observations of firms that discontinued cooperation with clients, of which 16 begin a new cooperation agreement with suppliers, 19 with clients, 9 with competitors and 9 with institutions. We also have 134 observations of firms that interrupted their agreements with competitors, of which 18 started to cooperate with suppliers, 14 with clients, 19 with competitors and 15 with institutions. Finally there are 571 observations of firms that interrupted their innovative relationships with research institutions, of which 33 started a new agreement with suppliers, 12 with clients, 13 with competitors and 89 with institutions.

To test our propositions, we estimate two models: a model in which we explain the propensity of a firm to engage in new cooperation with customers, suppliers, competitors and universities/research institutes and an innovation performance model in which we test an impact of new, continuous, and discontinued cooperation on firm's innovative performance. Below we explain how we measure the variables used in the estimation.

3.2 Dependent variable in the propensity to engage in new cooperation model

The propensity to engage in new cooperation model consists of four binary choice equations. Each of the four dependent variables in the model is a binary (yes/no) indicator of new cooperation that a firm is engaged in with respectively, suppliers, customers, competitors and universities/research institutions. For example, new customer cooperation takes the vale 1 if a firm reported engagement in cooperation with a customers in the survey of year *t* but not in the survey of year *t-1*[1]. The indicators of new supplier, new competitor and new university cooperation are constructed similarly.

3.3 Independent variables in the propensity to engage in new cooperation model

Our first independent variables are the preceding *new*, *continuous* and *discontinued* cooperation with suppliers, clients, competitors and universities/research institutions, respectively. Preceding new cooperation with customers, for example, takes value 1 if a firm was cooperating with customers in period t-1 but not in period t-2. Otherwise it is zero. Preceding new cooperation with suppliers, competitors and universities/research institutions are constructed in the same way. The variable *continuous cooperation* takes value 1 if a firm was engaged in cooperation with a particular type of partner in period t-1 and in period t-2, else zero. Therefore, we consider that a firm is a continuous cooperator (with a particular type of partner) if it reports to be engaged in cooperation with the same type of partner in two consecutive surveys. Since each survey refers to a period of three years a continuous cooperator is a firm that has been cooperating continuously or multiple times with the same type of partner during at least four consecutive years. The variable *discontinued cooperation*

[1] Questions on cooperation activities in the survey refer to cooperative agreements formed the last three years. That is to say, if a firm responds that it has cooperated, in the 2008 questionnaire, it means that it has cooperated at least in 2006 or 2007 or 2008 or during some or all of those years. This characteristic, similar to other innovation surveys, does not constitute an impediment to create our set of cooperation variables. Cooperative activities of the survey in year *t* refer to collaborative agreements carried out during t, t-1 and t-2; and the survey in year t-1 refers to t-1, t-2 and t-3.

takes value 1 if a firm was engaged in cooperation with a corresponding type of partner in period t-2 but not anymore in period t-1, else zero.

To test our hypothesis on the relationship between firm's innovativeness and its propensity to engage in cooperation, we include in each of the four binary choice equations a *past innovative performance* variable. It is defined as the firm's innovative productivity (logarithm of the ratio of sales from products which are new to the market divided by the total number of employees), in deviation of the industry mean, at the 2-digit according to the CNAE-93[2] classification. We expect a non-linear relationship between past innovative performance and the propensity to engage in new cooperation, and therefore include the square term of the past innovative performance in each of the four equations.

We also include an R&D input variable (ratio of innovation expenditures to sales), in line with the previous literature that documented a positive relationship between research & development intensity and propensity to cooperate. Following previous theoretical and empirical work, we expect this relationship to differ depending on the type of cooperation partner. In case of cooperation with competitors, the impact of R&D intensity is expected to be weaker than in case of vertical or institutional cooperation. A large R&D base is likely to be associated with stronger proprietary knowledge and greater risks of outgoing knowledge flows when cooperating with competitors. These risks are less significant when cooperating with vertical partners or universities. In line with the existing literature we include firm size (logarithm of the number of firm's employees). Larger firms are expected to have a bigger propensity to engage in (multiple) cooperation agreements, because they are more likely to be engaged in multiple technologies that may require various partnerships (Tether 2002; Freel 2003; Colombo and Garrone 1996; Bayona, Garcia-Marco et al. 2001; Hernan, Marin et al. 2003; Becker and Dietz 2004; Belderbos et al. 2004; Cassiman and Veugelers 2006; Morandi

[2] The CNAE 93 Rev.1 is a classification of economic activities prepared in accordance with conditions stipulated in the Rules of implementation of CNAE Rev. 1.1.

2007). In addition, large well-known companies are considered as the more attractive partners. To take into account the effect of firm's export orientation we include a dummy variable which takes value 1 if the firm is an exporter, zero else. Firms operating in international markets are exposed to greater competitive pressures, and they need to be more innovative gaining access to external knowledge and resources. Therefore we expect that exporters have a higher probability of establishing new alliances with all types of partners. Finally, we include a set of industry dummies and year dummies to take into account possible industry and time differences affecting new cooperation agreements.

3.4 Dependent variable in the innovation performance equation

In order to test our hypotheses pertaining to the effect of new, continuous and discontinued cooperation on firm's innovation performance we estimate a model in which the dependent variable is the firm's innovative productivity (logarithm of the ratio of sales from products which are new to the market divided by the total number of employees), in deviation from the industry mean, defined at the 2-digit level. This measure captures the innovative position of the firm relative to that of the firm's competitors.

3.5 Independent variables in the innovation performance equation

To test our expectations with respect to the impact of cooperation on innovation performance we include in the performance equation past new, continuous and discontinued cooperation variables with each of the four types of partners. Similarly to the propensity to cooperate model, we control for R&D intensity following previous studies that found that firms that expend more resources on R&D also record a better innovative performance (Cincera et al. 2004; Lööf 2009). We control for the export status as we expect that exporters are more innovative than non-exporters, all else being equal, since a firm needs to be more innovative

in order to successfully compete in the international markets. Further control variables include firm size (measured as logarithm of the firm's number of employees) and a set of 2-digit industry dummies (we distinguish 47 industries) as well as time dummies.

3.6 Modeling approach

In order to analyze the propensity of firm *i* to engage in new cooperation we estimate the four binary choice equations for horizontal (competitor), customer, supplier and institutional (universities and research centers) cooperation jointly. We have four binary dependent variables y_{i1}, y_{i2} , y_{i3} and y_{i4} where

$$y_{i,k} = \begin{cases} 1 & if \quad x_k \beta_k + \omega_k > 0 \\ 0 & otherwise \end{cases}, \qquad k = 1,...,4; \quad i = 1,...,N \tag{1}$$

and $(\omega_1\ \omega_2\ \omega_3\ \omega_4) \sim N(0, \Sigma)$ where Σ is the covariance matrix of the error terms. The error terms are likely to be correlated if only because of omitted variables in these choice processes. In case one does not take this into account, for example with four separate probit equations, inefficient estimators result. To capture the possible interdependence of yes-or-no decisions we employ a multivariate limited dependent variable (multivariate probit) model (e.g., Greene, 2002). We estimate the model via a simulated maximum likelihood estimator (Roodman, 2011) .

To test the impact of new, continuous and discontinued cooperation on innovation performance we estimate the following performance equation:

$$\begin{aligned} InnoPerf_{i,t} = \alpha + \sum_{n=1}^{4} \beta_{n=(cu,su,co,un)} NewCoop_{n,i,t-1} + \sum_{n=1}^{4} \delta_{n=(cu,su,co,un)} ContCoop_{n,i,t-1} + \\ + \sum_{n=1}^{4} \gamma_{n=(cu,su,co,un)} DiscontCoop_{n,i,t-1} + \eta W_{i,t-1} + \theta InnoPerf_{i,t-1} + \mu_i + \lambda_t + \varepsilon_{i,t} \end{aligned} \tag{2}$$

where *co*=competitor cooperation, *su*= supplier cooperation, *cu*=customer cooperation, and *un*=cooperation with universities and research institutes. The variable *W* stands for a set of

predetermined variables. Lagged *InnoPerf* is the level term of the dependent variable taken from the previous survey. Innovation performance has been found to be a persistent phenomenon: firms that are highly innovative and are at the frontier of innovation productivity are expected to be so in the subsequent periods. In the case of persistency we expect θ to fall within the interval [0, 1]. If θ is zero, this effect is absent. We include industry dummies (μ_i) and time dummies (λ_t). That is, the μ_i are assumed equal across firms in the same industry. We estimate equation (2) with OLS method with robust (clustered) standard errors. Incorporating firm-specific fixed or random effects next to the lagged dependent variable in a (very) short panel would introduce important challenges for estimation (OLS would lead to biases). The time dimension of the panel is too short to embark on dynamic panel estimation techniques such as GMM. We incorporate industry-specific effects and assume that persistence for firms is largely corrected for by including the lagged dependent variable. Table 1 shows summary statistics of the variables used in the models (1) and (2).

4. RESULTS

The first part of Table 2 displays the results of the multivariate probit model for each type of cooperative partner (suppliers, customers, competitors and research institutions). A simultaneous estimation is required since firms may start, at the same time, a new cooperative relationship with different partners. The second part of Table 2 shows the correlations between the residuals of each probit model for each partner, with the purpose of determining whether the likelihood of establishing a new relationship with a particular partner is affected by the fact that the firm is also starting a new agreement with other type of partner at the same

time. All the correlations are significant which implies that we have to take this effect into account by running a simultaneous model[3].

The results reveal several significant relationships between past innovative cooperation and the likelihood of establishing new alliances with the same or other types of partners. First, firms that interrupted their cooperative relationships with a particular type of partner in the past, have a higher probability of establishing a new partnership with that type of partner in the future. This is due to the fact that the effectiveness of R&D collaboration is conditioned by the firm's previous experience in this area. Therefore firms that gained experience in collaboration with a particular partner, that is to say firms that interrupted their relationships with that type of partner, have a higher probability of starting a new relationship with that type of partner in the future. This holds for every type of partner (suppliers, customers, competitors and research institutions). Although there are no studies which specifically analyze the influence of interrupted cooperation on the probability of establishing a new relationships with the same partner; this result confirms a finding already found in other studies, which is nothing more than the positive influence of previous experience in cooperation on the likelihood of engaging in this type of technological activities (Levinthal and Fichman, 1988, Oster, 1994; Saxton, 1997).

Regarding the effect of interrupted cooperation on new collaboration, we observe that those firms interrupting their relationships with competitors have a higher probability of establishing new alliances with clients. Since firms that compete in the same market share the same customer base, they do not start to cooperate with their clients until they have finished their agreement with their rivals. The main objective of R&D collaboration with clients is the adaptation of products to customers' preferences, which is normally related with product differentiation, to gain market share. Miotti and Sachwald (2003) suggest that cooperation

[3] Note that we have also run individual probit estimations, without finding any important change to the results.

with rivals is not normally associated with firms' core innovative activities. While cooperation with clients is strongly linked to their main activity, this could also explain why cooperation with one type of partner does not increase the probability of establishing a new relationship with the other. Moreover, cooperation with competitors does not lead to the formation of new innovative linkages with other partners; in fact it even appears to overlap less often with other cooperative agreements. This could occur because competitor collaborative R&D projects are broader in scope and require less complementary simultaneous research and development efforts with other allies. Proposition 5 is only partially supported.

Additionally, results show that firms which have interrupted their agreements with research institutions are more likely to establish new technology partnerships with competitors. Firms might start cooperating with research institutions, in order to get access to fundamental knowledge and basic research, and then they develop applied research together with their competitors. There is also some evidence for an effect of ending cooperation with suppliers to starting new cooperation with clients. This largely follows the flow of activities in the supply chain. The rest of the interrupted cooperation variables do not affect significantly the likelihood of establishing new alliances with other partners.

Results indicate that previous cooperation (new or continuous) with a particular type of partner increases the probability of establishing new agreements with other type of partners. This implies support for Proposition 2. We observe that there is a strong inter-linkage between clients and supplier collaboration; firms that cooperated with clients (suppliers) are more likely to establish new agreements with suppliers (customers). This result highlights the advantages of performing an innovative activity through the vertical chain (Belderbos et al, 2011). Therefore we observe a process of vertical integration in the formation of R&D networks. This supports Proposition 3. Although there are no previous

studies analyzing this relationship, certain authors suggest that cooperation with suppliers and customers is related to the search of technological complementarities (Van Looy et al. 2005). The integration of R&D activity with clients and suppliers is positively related with product innovations, since their interaction generates synergic effects (Mcdermott and Handfield 2000; Lee 2000; Frohlich and Westbrook 2001; Ragatz et al. 2002; Chesbrough 2003). Suppliers and customers play an important role in the innovation process, contributing with information about technology, the needs of users and the characteristics of markets (Miotti and Sachwald 2003).

We also find similarly strong relationships for suppliers and research institutions as we find for suppliers and customers. Firms cooperating with suppliers (research institutions) are more likely to establish new relationships with research institutions (suppliers). This result is not surprising since suppliers and research institutions are the most common types of partners employed by Spanish firms. In Spain the majority of the national R&D effort is carried out by the public sector, therefore firms have an incentive to cooperate with research institutions and, moreover, these types of linkages are supported by public policies. Also, Spanish companies are less vertically integrated compared with firms from other European countries. This implies that Spanish firms consider cooperation with their suppliers as a very important strategy. Since these partners are the most used by Spanish firms it is logical that one partner leads to the other. Moreover, having experience in collaboration with research institutions (including universities) is an antecedent of new collaborative agreements with other partners (like competitors). Innovative cooperation with research institutions is related with basic research and more generic knowledge and technology which can be exploited later in other collaborative projects (Veugelers and Cassiman, 2005). This provides support for Proposition 4.

Regarding the relationship between innovative performance and the likelihood of establishing new R&D agreements, we see that the most innovative firms of each industry are more likely to start new agreements with suppliers and institutions; which is likely to be due to the fact that they are more attractive collaboration partners. However this is not the case with horizontal (competitor) cooperation. Although the more innovative firms of each industry tend to cooperate more with competitors, the innovative leaders have a smaller probability of establishing new relationships with competitors. Here the risk of dissipation of knowhow to rivals - with direct detrimental effects on the firm's market position -is discouraging R&D collaboration and performance has a negative effect on the new R&D collaboration propensity. This is all in line with Proposition 6.

The results also show that larger firms, more R&D intensive firms and exporters are more likely to establish new cooperative agreements as we expected.

Results for Innovative Performance

The results of the equation analyzing the effect of previous cooperation on firms' innovative productivity differential are displayed in Table 3. We find a strong influence of past innovative performance and R&D intensity on current innovative performance, yet R&D cooperating significantly improves the fit of the model. The results confirm that continuous cooperation is most effective, followed by new cooperation and interrupted cooperation. This is in line with Proposition 1. There is no significant positive (but also no negative) effect of interrupted collaborative innovative activities. Firms cooperating with research institutions exhibit a higher innovative performance which may be due to the fact that they may involve radical innovations, which are most likely to be the result of long term collaborative efforts and collaboration with universities and public research institutes. We also find that larger firms, more R&D intensive firms and exporters are more innovative.

CONCLUSIONS

Whereas prior studies have either examined the performance effects of R&D collaboration, or the determinants of the decision to engage in R&D collaboration, this study examines the interrelationship between innovative performance and collaboration. We distinguish between cooperation with suppliers, clients, competitors and research institutions. Using yearly panel data on a large set of Spanish innovating firms, we can examine dynamic patterns in R&D collaboration as antecedents of future collaboration and performance. In contrast with earlier work using Community Innovation Survey data, we are able to analyze the propensity to set up new R&D collaboration agreements, rather than the propensity to be engaged in collaboration per se.

We find evidence of a -complex- two way relationship between innovative performance and collaboration. While firms with better past innovative performance (in terms of sales of 'new to the market' products) are in general more likely to set up new collaborative agreements subsequently, which is likely to be due to the fact that they are more attractive collaboration partners, this is not the case for 'horizontal' collaboration with competitors. Here the risk of dissipation of knowhow to rivals - with direct detrimental effects on the firm's market position -is discouraging R&D collaboration and performance has a negative effect on the new R&D collaboration propensity. Firms that are collaborating with one type of partner are also more likely to establish cooperation with other types of partners. These interlinkages are particularly strong between client and supplier collaboration and indicate the advantage of collaboration through the vertical chain, confirming results of previous analyses (Belderbos et al, 2011). Prior collaboration with public research institutions (including universities) is an antecedent of new collaborative agreements with all three other partner types. The more generic knowledge and technologies that are generated in public institute collaboration can be

exploited in other collaborative projects (Veugelers and Cassiman, 2005). In contrast, collaboration with competitors does not directly lead to the formation of additional collaborative ties with other partners and appears to overlap less often with other collaborative efforts. A possible explanation is that competitor collaborative R&D projects are broader in scope and require less complementary simultaneous research and development efforts with other partners, while overlapping vertical and horizontal alliances are subject to much more complex governance issues, such that consecutive collaboration strategies are more likely (Belderbos et al, 2011).

Current innovative performance is strongly related to past performance and R&D investments, yet R&D collaboration can significantly improve it. Firms that have been collaborating with a type of partner over a longer period can improve performance. Among partner types, cooperation with research institutions is the most likely to pay off. Generating product innovations with market impact often requires 'radical' innovations, which are most likely to be the result of long term collaborative efforts and collaboration with universities and public research institutes.

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Table 1. Descriptive Statistics

	Mean	Stdev	Min	Max
Innovative productivity	0.201	1.748	-1.99	9.77
New Coop. Suppliers	0.024	0.153	0	1
New Coop. Clients	0.006	0.08	0	1
New Coop. Competitors	0.007	0.083	0	1
New Coop. Institutions	0.027	1.633	0	1
New Coop. Suppliers $_{t-1}$	0.022	0.146	0	1
New Coop. Clients $_{t-1}$	0.006	0.078	0	1
New Coop. Competitors $_{t-1}$	0.006	0.079	0	1
New Coop. Institutions $_{t-1}$	0.028	0.166	0	1
Continuous Coop. Suppliers	0.043	0.204	0	1
Continuous Coop. Clients	0.008	0.092	0	1
Continuous Coop. Competitors	0.007	0.085	0	1
Continuous Coop. Institutions	0.045	0.207	0	1
Interrupted Coop. Suppliers	0.025	0.158	0	1
Interrupted Coop. Clients	0.005	0.076	0	1
Interrupted Coop. Competitors	0.007	0.083	0	1
Interrupted Coop. Institutions	0.03	0.171	0	1
Size $_{t-1}$	4.116	1.49	0	10.633
R&D Intensity $_{t-1}$	0.059	0.119	0	0.999
Exporting Firm $_{t-1}$	0.686	0.463	0	1
Innovative productivity $_{t-1}$	0.214	1.724	-1.99	9.769

Table 2. Determinants of new cooperation with suppliers, clients, competitors and research institutions

	New Supplier Cooperation	New Customer Cooperation	New Competitor Cooperation	New Institutional Cooperation
Innovative productivity $_{(t-1)}$	0.078*** (0.020)	0.005 (0.031)	0.106*** (0.032)	0.057*** (0.020)
Innovative productivity squared $_{(t-1)}$	-0.005 (0.006)	0.019** (0.009)	-0.025** (0.012)	-0.006 (0.007)
New Supplier Coop $_{(t-1)}$		0.546*** (0.157)	0.308* (0.160)	0.635*** (0.108)
New Customer Coop $_{(t-1)}$	0.618*** (0.242)		0.661*** (0.197)	0.393* (0.232)
New Competitor Coop $_{(t-1)}$	0.281 (0.232)	-0.174 (0.337)		0.379 (0.268)
New Institutional Coop $_{(t-1)}$	0.623*** (0.103)	0.274* (0.157)	0.325** (0.152)	
Continuous Supplier Coop		0.480*** (0.133)	-0.005 (0.145)	0.290*** (0.107)
Continuous Customer Coop	0.519* (0.279)		0.455** (0.194)	0.369* (0.205)
Continuous Institutional Coop	0.595*** (0.096)	0.228* (0.136)	0.458*** (0.131)	
Interrupted Supplier Coop	0.706*** (0.097)	0.276* (0.151)	-0.048 (0.147)	0.123 (0.110)
Interrupted Customer Coop	0.139 (0.189)	0.929*** (0.185)	0.361 (0.228)	0.053 (0.221)
Interrupted Competitor Coop	0.280 (0.179)	0.456** (0.187)	0.936*** (0.157)	0.296 (0.192)
Interrupted Institutional Coop	0.062 (0.105)	0.161 (0.145)	0.291** (0.142)	0.720*** (0.084)
Size$_{(t-1)}$	0.143*** (0.016)	0.147*** (0.024)	0.122*** (0.024)	0.101*** (0.015)
R&D Intensity$_{(t-1)}$	0.810*** (0.175)	1.444*** (0.024)	0.325 (0.307)	0.916*** (0.155)
Exporting Firm	0.341*** (0.063)	1.411*** (0.223)	0.345*** (0.092)	0.257*** (0.057)
Constant	-3.110*** (0.136)	-4.177*** (0.219)	-3.423*** (0.208)	-2.279*** (0.152)
Pseudo R-squared	0.1408	0.1961	0.1688	0.1045

	Rho1	Rho2	Rho3
Rho/2	0.736*** (0.035)		
Rho/3	0.645*** (0.036)	0.703*** (0.043)	
Rho/4	0.731*** (0.224)	0.574*** (0.044)	0.713*** (0.033)
Observations	18052		
LL	-4384.2257		
Wald chi^2 (57)	596.27		

Notes: 46 industry dummies (reference group: mechanics) and 2 year dummies (reference year: 2006) included.
**Significant at 10%, **Significant at 5%, ***Significant at 1%*

Table 3. The effect of past cooperation on innovative productivity

	Innovative productivity
Innovative productivity $_{(t-1)}$	0.641*** (0.007)
New Supplier Coop $_{(t-1)}$	0.013 (0.075)
New Customer Coop $_{(t-1)}$	-0.033 (0.139)
New Competitor Coop $_{(t-1)}$	-0.015 (0.127)
New Institution Coop $_{(t-1)}$	0.248*** (0.067)
Continuous Supplier Coop	0.050 (0.064)
Continuous Customer Coop	0.207 (0.126)
Continuous Competitor Coop	0.269** (0.138)
Continuous Institution Coop	0.237*** (0.061)
Interrupted Supplier Coop	0.110 (0.072)
Interrupted Customer Coop	-0.057 (0.146)
Interrupted Competitor Coop	0.004 (0.129)
Interrupted Institution Coop	0.049 (0.063)
$Size_{(t-1)}$	0.018** (0.007)
$R\&D\ Intensity_{(t-1)}$	0.973*** (0.107)
$Exporting\ Firm_{(t-1)}$	0.155*** (0.023)
Constant	-0.188*** (0.067)
Observations	19,100
R-squared	0.4276

Notes: 46 Industry dummies (reference group: mechanics) and 2 year dummies (reference year: 2006) included.
**Significant at 10%, **Significant at 5%, ***Significant at 1%*

APPENDIX: Definition of variables

Innovative productivity	Ln("New Sales" / Employees) - Ln(Industry average of "New Sales" / Employees). It is the difference between the firm's innovative productivity (where "New Sales" is sales due to new products) and its industry mean.
New Coop. Suppliers	1 if the business unit reported engagement in innovation with suppliers in year t but not in t-1, else 0
New Coop. Clients	1 if the business unit reported engagement in innovation with clients in year t but not in t-1, else 0
New Coop. Competitors	1 if the business unit reported engagement in innovation with competitors in year t but not in t-1, else 0
New Coop. Institutions	1 if the business unit reported engagement in innovation with research institutions in year t but not in t-1, else 0
Continuous Coop. Suppliers	1 if the business unit reported engagement in innovation with suppliers in the previous past two years (t-1 and t-2), else 0
Continuous Coop. Clients	1 if the business unit reported engagement in innovation with clients in the previous past two years (t-1 and t-2), else 0
Continuous Coop. Competitors	1 if the business unit reported engagement in innovation with competitors in the previous past two years (t-1 and t-2), else 0
Continuous Coop. Institutions	1 if the business unit reported engagement in innovation with research institutions in the previous past two years (t-1 and t-2), else 0
Interrupted Coop. Suppliers	1 if the business unit reported engagement in innovation with suppliers in t-2 but not in t-1, else 0
Interrupted Coop. Clients	1 if the business unit reported engagement in innovation with clients in t-2 but not in t-1, else 0
Interrupted Coop. Competitors	1 if the business unit reported engagement in innovation with competitors in t-2 but not in t-1, else 0
Interrupted Coop. Institutions	1 if the business unit reported engagement in innovation with research institutions in t-2 but not in t-1, else 0
Size	Logarithm of number of employees
Innovation Intensity	Total innovation expenditures divided by sales. Innovation expenditures include, in addition to internal expenditure on R&D, the acquisition of external R&D, i.e. acquisition of machinery, equipment, hardware and advanced software, external knowledge for innovation, training costs, and expenses to introduce innovations in the market and design costs, production and distribution of innovations
Exporting firm	1 if the business unit sells products outside Spain, else 0