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Exploration during turbulent times: an analysis of the effects of R&D cooperation on radical innovation performance during the economic crisis

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Abstract

During the recent economic recession, firms have been less willing to invest in innovation, which often is an uncertain and long-term process. This reduction did not occur equally for all firms, and recent literature has analysed the characteristics of those firms which maintain or even raise their innovative efforts during the crisis. Technological collaboration has been recognized as one of the most important external sources that affects innovation performance. However, how economic recession has changed the impact of R&D collaboration on innovation performance has received few attention. This paper investigates the effect of different external cooperation patterns of firms before and during the last economic recession. We highlight the role of geographical and organizational diversity of knowledge sources, as well as the effect of past experience. We find that R&D cooperation has a stronger effect on radical innovation performance during the economic recession than before the crisis. The positive effect on innovation performance is stronger during the crisis than before irrespectively of the geographical location of partners. When the firm cooperates with a variety of international partners (organizational diversity), the during-crisis effects of cooperation are generally stronger than before the crisis. In addition, we also find that past experience in R&D cooperation positively affects innovation performance during the crisis.

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1 Introduction

During economic recessions, firms face a major decrease in demand, financial constraints, and uncertainty about future market opportunities. These conditions might induce firms to reduce their investments in innovation; as a consequence, their innovation output could be negatively affected (OECD, 2009). At the same time, the economic turmoil could offer new learning opportunities (Chesbrough and Garman, 2009). Within this scenario, R&D cooperation – which is one of the means the firms use to purse innovation (Tether, 2002) – could either become less important for achieving innovation performance during the crisis or alternatively could offer new opportunities to cope with the challenges of the crisis by boosting innovation performance. While several studies have investigated the effects of economic crises on R&D expenditures (Archibugi et al., 2013a, 2013b; Cincera et al., 2012a) and innovation output (Madrid-Guijarro et al., 2013), little is known about how the crisis has affected R&D cooperation and its impact on innovation performance.

The relation between business cycles and innovation is far from consensus. The countercyclical approach proposes that during recessions innovation increases as, with low demand, the opportunity costs of doing innovation is higher than in periods of growth (Aghion and Saint-Paul, 1998; Schumpeter, 1939). Alternatively, the procyclical approach points out that financial constraints might prohibit the firms to maintain or increase their R&D budget (Stiglitz, 1993) and that firms postpone innovation to periods of expansions to maximize the returns (Barlevy, 2004). Strategy literature has stressed the idea that learning is a crucial capacity of the firm (Kogut and Zander, 1992) and under changing external environmental firms react by adapting their learning process (Lavie and Rosenkopf, 2006; March, 1991; Posen and Levinthal, 2012). In particular, under turbulent environment firms might opt for an exploration strategy (e.g. more search, experimentation and risk taking) (March, 1991), of which R&D cooperation is a possible means (Koza and Lewin, 1998). Therefore, R&D cooperation could offer learning opportunities even during a turbulent time such as an economic recession, and can constitute a specific strategy to face economic crises.

The empirical evidence of the effects of the economic crisis on innovative investments is mostly supporting the procyclical arguments (Archibugi et al., 2013a, 2013b; Cincera et al., 2012a; Madrid-Guijarro et al., 2013; OECD, 2009; Paunov, 2012). Some of these scholars have explored the characteristics of firms that have increased their innovative investments during the crisis, showing that recessions do not hit all firms equally and that some strategies could help to face a turbulent climate. Among other characteristics, an explorative behaviour (e.g. searching for new market opportunities) has been found correlated to increasing innovation during the economic recession (Archibugi et al., 2013a, 2013b).

By drawing on the literature on business cycle and innovation (Aghion and Saint-Paul, 1998; Barlevy, 2004), and the strategy literature that has explored how firms adapt their learning processes to changing environment (March, 1991; Posen and Levinthal, 2012), this paper explores whether R&D cooperation helps to improve innovation performance during an economic recession. R&D collaboration with external partners has been recognized as an important determinant of firms' innovation performance (Becker and Dietz, 2004; Nieto and Santamaría, 2007). We expect that, when facing turbulence, an exploration strategy such as R&D cooperation results as a successful strategy to adapt to changing environment by acquiring new knowledge that are far from existing knowledge stock (March, 1991; Posen and Levinthal, 2012). This can be especially true in the case of innovation that incorporates a high level of innovativeness such as radical-innovative products, for which external and diversified sources may imply knowledge that differs significantly from the one already present in the firm.

We use data from the Spanish Technological Innovation Panel for the period 2004–2013 and we estimate a two-stage selection model (Wooldridge, 1995). In the first-stage selection equation, the dependent variable indicates whether or not the firm has invested in innovation. The second stage of the analysis estimates the effects of collaboration on innovative performance. For the purpose of our analysis, we compare these effects before and after the crisis. We assess not only the impact of any type of R&D cooperation, but we also qualify R&D collaboration along two dimensions: geographical (i.e. exclusively-national versus international partners), and organizational (i.e. whether the firm collaborates only with one type of partners or with multiple ones). In addition, we investigate the impact of past experience in R&D collaboration in the during-crisis years.

The paper is organised as follows. Section 2 reviews the literature on innovation and economic crisis, and on the effect of R&D cooperation on innovation performance.

The data and the model are presented in Section 3 and a descriptive analysis is provided in Section 4. Econometric results are examined in section 5. Finally, Section 6 draws some conclusions.

2 Literature review

2.1 R&D cooperation during economic crises

The relation between business cycles and innovation could be countercyclical or procyclical (Aghion and Saint-Paul, 1998; Barlevy, 2004; Geroski and Walters, 1995; Stiglitz, 1993). The countercyclical approach relies on the Schumpterian perspective (Schumpeter, 1939) that in recessions innovation increases as firms would focus more on productivity-enhancing activities, and less on production activities because demand is low. Since production and R&D compete for resources, decreasing growth rates could be a good moment to devote more resources to R&D; hence, the incentive of carrying out innovation during recessions is higher than in periods of growing demand (Aghion and Saint-Paul, 1998). Alternatively, the procyclical approach debates that there are adverse conditions that inhibit the firms from maintaining or increasing their innovation efforts during recessions. One of the reasons is that recessions cause financial constraints, in terms of cash flows to devote to R&D and access to external financing to support R&D (Stiglitz, 1993). Another reason is that since the returns from innovation have a short time span (namely, until competitors learn how to imitate the successful new products), firms postpone the investments in innovation to periods of expansions to maximize the benefits (Barlevy, 2004).

Strategy literature has related changing external environments to the learning processes that the firms activate in order to survive, namely an explorative or exploitative approach (Koza and Lewin, 1998; Lavie and Rosenkopf, 2006; Levinthal and March, 1993; March, 1991; Posen and Levinthal, 2012). A key difference between stable and turbulent environments is the relative role of explorative and exploitative learning (Levinthal and March, 1993; March, 1991). Exploration implies search, discovery, experimentation, variation, flexibility, risk taking and innovation. Exploitation implies refinement, implementation, efficiency, choice, selection and production (March, 1991). When facing turbulence, an exploration strategy is necessary to adapt to changing environment and to acquire new knowledge that are far from existing knowledge stock (March, 1991; Posen and Levinthal, 2012). This applies not without caveats. Too much focus on new knowledge may lead to too many underdeveloped ideas (March, 1991), and

rewards to exploration can be eroded by ongoing turbulence, as the new knowledge accumulated during the changing environments can have short-term applications (Posen and Levinthal, 2012). Although both exploration and exploitation can be performed on internal as well as on external knowledge sources, exploration activities rely more heavily on external knowledge (Rosenkopf and Nerkar, 2001). R&D collaboration are explorative in nature, while other types of alliances (marketing alliances, or supplying alliances) are exploitative (Koza and Lewin, 1998). Hence, R&D cooperation could offer learning opportunities even during a turbulent time such as economic recessions, and can constitute a specific strategy to face the challenges of an economic crisis.

During economic recessions, firms could address their resources to explore new markets and technological fields (Archibugi et al., 2013a) through external collaborations and to upgrade the skills of the R&D workforce through contacts with external specialists (Barrett et al., 2009). Since market turbulence increases the uncertainty of doing innovation, R&D cooperation could offer a channel to increase the variety of knowledge sources (Miotti and Sachwald, 2003) and help the firms to monitor new opportunities that might arise in the near future (Archibugi et al., 2013a), as focusing solely on the exploitation of existing knowledge can damage the long-term capacities of a firm "to grow beyond its core business" (Chesbrough and Garman, 2009, p. 1). R&D cooperation could also relieve the financial pressures (Cincera et al., 2012a), because it allows firms to share the costs and risks of doing innovation and it may allow the firms to access to resources from partners in a better financial situation (e.g. private institutions, large corporations, or firms in fast-growing markets less affected by the recession).

The empirical evidence of the effects of economic crisis on overall innovative efforts is mostly supporting the procyclical arguments and some of these studies detect an explorative attitude in the firms that have increased their innovative investments during the last recession (Archibugi et al., 2013a, 2013b; Cincera et al., 2012a; Filippetti and Archibugi, 2011; Madrid-Guijarro et al., 2013; OECD, 2009; Paunov, 2012).

However, as far as our knowledge is concerned, the effects of economic recessions on the relations between R&D cooperation and innovation performance has not been studied. We expect that, despite the general level of R&D cooperation could have decreased during the last economic recession (i.e. R&D cooperation is pro-cyclical) as suggested by studies on overall innovation investments (Cincera et al., 2012a; Filippetti and Archibugi, 2011; OECD, 2009), the firms which managed to be innovative have used R&D cooperation as an exploration strategy to cope with the crisis. Therefore, the effects

of R&D cooperation on innovation performance during the last economic recession would be stronger than during the expansion, suggesting that the most innovative firms during economic recessions benefit from technological cooperation with external partners to a larger extent than in expansion times.

2.2 The geography of R&D cooperation during economic crises

During an economic downturn, focusing solely on national partners can offer an exploration strategy with relatively lower risks, as firms move outside their boundaries but within their National Systems of Innovation (NSI) (Cantwell, 1989; Lundvall, 1992; Porter, 1990). National firms share the same problems and difficulties within a NSI, and solutions from foreign countries might not be applicable. As a consequence, national R&D collaboration could offer the possibility to share the costs of exploring opportunities under a common changing environmental.

In comparison to national R&D cooperation, international R&D partners offer new learning opportunities not or scarcely available nationally, which eventually boost innovation performance (Arvanitis and Bolli, 2013; Badillo and Moreno, 2015; Frenz and Ietto-Gillies, 2009; Lavie and Miller, 2008; van Beers and Zand, 2014). Having cooperation agreements with international partners provide a wide knowledge and multiple communication channels that the firms are particularly willing to use during a recession. Firstly, international R&D cooperation can be a way to diversify the risk and escape the lock-in knowledge traps of own NSI, as partners reflect the technological strength and specialization of their home country NSI (Lundvall, 1992). Indeed, firms that count only on their home national innovation system can be more vulnerable when a recession hits the country. Secondly, in a period of low demand, international R&D cooperation could help to purse an exploration strategy in new or related technological fields, which are more likely to be found in foreign NSI. Thirdly, when under financial constraints, firms may have better chances to share costs when the partner is international, either because the crisis hits NSI differently (some foreign countries had the resources to continue to support business R&D, see e.g. Hud and Hussinger (2015) about Germany) or because some large players operating at international level might be less affected from a decrease of cash flows.

2.3 R&D cooperation and the diversity of partners during economic recessions

Firms collaborate with different type of actors. R&D collaborations with suppliers and clients provide vital information on technologies, markets and user's need (Miotti

and Sachwald, 2003). Horizontal cooperation is used to share the costs and risks of setting a standard technology or to comply to a new regulation (Tether, 2002). R&D collaboration with institutions usually involve low risk of knowledge leakage and it has increasingly become a crucial means to access to new scientific, basic, pre-competitive knowledge (Miotti and Sachwald, 2003), as it has increased over time for the incentive by governments to fund research oriented to increase competiveness of firms (Nieto and Santamaría, 2007).

Despite the fact that the choice of each type of partner depends on the strategy and resources of the firms, having multiple types of partners have been found to have a positive effect on innovation performance (Becker and Dietz, 2004; Nieto and Santamaría, 2007; van Beers and Zand, 2014). Indeed, a diversity of external sources of knowledge spurs synergies and novel associations, exposes the firm to skills and expertise from different technological fields (Chesbrough, 2003; Cohen and Levinthal, 1990; Laursen and Salter, 2006).

In time of economic turmoil, firms might decide to reduce the risks of having a broad network of partners, since too much openness could become costly and inefficient for the firm (Laursen and Salter, 2006). In addition, some benefits arise from focusing on a single type of partners, such as the development of certain routines that facilitate knowledge exchange (Belderbos et al., 2015). However, the benefits of relying on a variety of sources could be higher than the ones from having a single type of partners, especially during a crisis. Hence, the diversity of type of partners should spur innovation performance more intensively during economic crises.

In addition, if these partners are international, the combination of diversity of partners and diversity of home-country NSI of partners should reinforce the effects on innovation performance. In this case, not only firms benefit from specialized knowledge coming from different types of partners, but also they are able to access to different knowledge bases of foreign NSI, as discussed in Section 2.2.

2.4 The importance of time: continuity and persistence in R&D cooperation

Previous experience in technological cooperation might help the firms in different ways (Belderbos et al., 2015; Nieto and Santamaría, 2007; Rothaermel and Deeds, 2006). If the repeated collaboration regards the same type of partners (e.g. suppliers, clients, competitors, institutions), the firms could have developed some mutual routines and capabilities to deal with problems, which during an economic turmoil can constitute an

advantage towards firms that have not a history of accessing to external sources of knowledge.

The literature on the patterns of the previous experience in R&D collaboration has highlighted that the quantity of collaboration done in the past is only a part of the story. Indeed, high levels of alliance activity have diminishing returns (Rothaermel and Deeds, 2006; Sampson, 2005). One possible explanation for that is that only the most recent experience offers lessons, especially under changing external environment (Samson 2005). In addition to that, Belderbos et al. (2015) find that mostly the persistent collaboration (i.e. in two previous consecutive years) is important for innovation performance.

Although the recent experience offers the most valuable knowledge, the firms that have pursed an explorative behaviour under different business climates could benefit of a variety of knowledge. Indeed, as the external knowledge acquired during a certain period become part of the current knowledge stock of firms, the combination of past external knowledge and current external knowledge could boost new innovative ideas (Kogut and Zander, 1992). Accordingly, firms which have cooperated both before and during the crisis may have higher innovative performance than firms that have cooperative agreements only before or only during the crisis.

3 Data and the model

3.1 Data

Our empirical analysis uses data from the Spanish Technological Innovation Panel (PITEC) [1] from 2004 to 2013. Our initial unbalanced sample includes 85755 observations, with represents 10917 manufacturing and service firms with at least ten employees and positive sales, and which did not report any significant event that would impact employment. Since this sample decreases over time because some firms may report a major issue[2], we test our predictions on a balanced panel of firms that are present during the period 2005-2013[3]. This balanced panel comprises 53595 observations, representing 5955 firms.

[1] This database is available at http://icono.fecyt.es/PITEC

[2] Possible issues reported are: firms belonging to a sector with high employment turnover; acquired firm; change in the unit of reference; change or abandonment of activity; firm remaining of an acquisition process (not part of the acquisition); in liquidation; merged; firm which has employees ceded by other firms; consequence of the crisis; firm which cedes employees to other firms.

[3] The sample size in 2004 is lower than 2005 and subsequent years. Hence, imposing the restriction of the balanced panel to firms present in 2004-2013 would have left new firms entering in 2005 and staying for the remaining years.

3.2 The model

We follow a two-stage approach to address the potential selection bias on the estimation of the innovation performance equation. The first stage consists of a binary selection model using all sample observations and considering as dependent variable whether the firm has carried out innovation activities[4] and 0 otherwise (d). The second stage consists in the estimation of the innovation performance equation, the dependent variable being innovative performance (y), taking explicit account of the selection process.

The specification of the model is as follows:

$$d_{it}=1[z_{it}\gamma+\eta_i+u_{it}>0], \tag{1}$$

$$y_{it}=\begin{cases} x_{it}\beta+\alpha_i+\varepsilon_{it} & if\ d_{it}=1 \\ 0 & if\ d_{it}=0 \end{cases} \tag{2}$$

with i = 1, …, N, t = 1, …, T, and 1[.] an indicator function that takes on the value 1 if the expression between square brackets is true and 0 otherwise; γ and β are unknown parameter vectors to be estimated and z_{it} and x_{it} are vectors of explanatory variables with possibly common elements. Valid exclusion restrictions are assumed in equation (2). η_i and α_i are unobserved individual specific effects which may be correlated with z_{it} and x_{it}, respectively; and u_{it} and ε_{it} the idiosyncratic errors. The innovation performance variable (y_{it}) is only observable if the firm made an innovative investment ($d_{it}=1$) and the parameter vector of interest to estimate is β.

We use the Wooldridge's (1995) consistent estimator for panel data with sample selection. First, we consistently estimate β by estimating a probit of d_i on z_i for each t and then saving the inverse Mills ratio, $\hat{\lambda}_{it}$. Second, the method estimates by pooled OLS the equation of interest augmented by the inverse Mills ratio and the means of the time-varying explanatory variables (x_i) using the selected sample.[5] The resulting equation is (Wooldridge, 2010):

[4] These activities include: internal R&D; external R&D, acquisition of machinery, equipment and software; acquisition of other external knowledge; training; market introduction of innovations; other preparations.

[5] We assume that the conditional mean of the individual effects are a linear projection on the within individual means of the time-variant regressors (Mundlak, 1978; Nijman and Verbeek, 1992; Wooldridge, 1995; Zabel, 1992).

$$y_{it} = x_{it}\beta + x_i\psi + \sum_{t=1}^{T} \rho_t D_t \hat{\lambda}_{it} + e_{it} \quad \text{for all } d_{it}=1 \qquad (3)$$

where D_t is a time indicator variable.

In order to compare the cooperation behaviour before and during the crisis, we firstly estimate Eq. (3) for whole period (t = 2004, …, 2013), with 1-year lag of time-variant regressors, both for the unbalanced and balanced panel. Secondly, we run Eq. (3) for the pre-crisis years (t = 2005, …, 2010), and for the during-crisis years (t = 2011, …, 2013) for the balanced panel to ensure comparability. These time frames build on the fact that the real economy was hit by the crisis in 2009 (European Commission, 2015; Hud and Hussinger, 2015; Keeley and Love, 2010) and that our cooperation variables refers to cooperation behaviour in the survey year t and in the previous two years. Hence, estimating the dependent variable in 2011 on 1-year lag cooperation means that we are considering cooperation behaviour in 2010, 2009, and 2008, meaning that during the crisis we allow for cooperation only in one possible year of overlapping with the pre-crisis period (i.e. 2008). Accordingly, estimating the dependent variable in 2010 on 1-year lag cooperation means that we are considering cooperation behaviour in 2009, 2008, and 2007, meaning that before the crisis we allow for cooperation only in one possible year of overlapping with the during-crisis period (i.e. 2009). There is no other overlapping in the rest of the years under consideration.

3.2.1 Dependent variables

In the first stage, the dependent variable is equal to 1 if the firm has been engaged in any innovation activity in t. In the second stage, the dependent variable is innovation performance, defined as the share of sales in t due to products new to the firm (new incrementally-innovative products) or to the market (new radically-innovative products), introduced in the survey year or in the previous two years. New-to-the-market products can be seen as more "radical" innovation since they push the technological frontier in the industry (Belderbos et al., 2015). We transform these shares as the ratio between the ratio of new sales on total sales and the complement to 1 of this latter ratio, and then transformed in logarithm. This measure has the advantage of being closer to a normal distribution and being symmetric (Barge-Gil, 2013; Raymond et al., 2010; Robin and Schubert, 2013). For the general model on the effect of R&D cooperation on innovation performance, we run separately models for incremental and radical innovation, while the remaining analysis is carried out only for the radical one.

3.2.2 Explanatory variables

In the first stage, building on an established literature on the determinants of innovation, we control for firm size (size) as the logarithm of number of employees, and we also introduce its squared term (size 2) to take into account nonlinearities; in addition, we insert market share as the ratio of the sales of a firm over the total sales of the two-digit industry it belongs to, and whether the firm belongs to a group (Raymond et al., 2010; Vega-Jurado et al., 2009; Veugelers and Cassiman, 1999). We also introduce barriers to innovation by means of four Likert-type variables: cost obstacles, knowledge obstacles, market obstacles, and other obstacles[6]. We allow a time lag of two years, since the dependent variable refers to innovation activities occurring in the year of the survey and in the previous two years. Finally, industry dummies are introduced at 2-digits CNAE-2009 classification.

In the second stage, the key explanatory variable is cooperation, which takes the value 1 if the firm declares to have undertook innovative activities with other enterprises or entities (external or from the same-group) in the survey year and the two previous years[7]. We qualify cooperation along two dimensions, geographical (i.e. the home-country of the partner) and organizational (i.e. the type of partner). We construct the variable national only, which is equal to 1 if the firm declares to have collaborated only with national partners, 0 otherwise; in addition, we build the variable international, which is equal to 1 if the firm declares to have collaborated at least with an international partner. By using the information on the type of partners, we identify three typologies: vertical (i.e. suppliers and clients), horizontal (i.e. with competitors or other firms in the same branch of activity), and institutional (i.e. university, private and public research centres, institutes, laboratory, consultants, or technological centres). We firstly identify the firms that cooperate exclusively with same-group national firms (national only same group only). Then, we identify the firms that were collaborating only with a type of national partner not from the same corporate group (henceforth, external)[8]: national only vertical only, national only horizontal only, and national only institutional only. In addition, we

[6] For each of these variables, we sum of the scores of importance that the firm attributed [number between 1 (not important) and 4 (very important)] to the factors that hampered its innovation activities, then rescaled from 0 (unimportant) to 1 (crucial) (2-year lag). In particular, for cost obstacles the factors are: lack of funds within the enterprise or enterprise group, lack of finance from sources outside the enterprise, innovation costs too high. For knowledge obstacles, lack of qualified personnel, lack of information on technology, lack of information on markets, difficulty in finding cooperation partners for innovation. For market obstacles, markets dominated by established enterprises, uncertain demand for innovative goods or services. For other obstacles, the factors are: not necessary due to previous innovations, not necessary due to the absence of demand.

[7] This cooperation does not require that the parts achieve a commercial benefit and it excludes subcontracting without active cooperation.

[8] Note that these firms may also have national or international cooperation with same-group firms.

introduce national only multi-partners, which takes the value 1 if the firm is cooperating with at least two different types of national external partners. As far as the international collaboration is concerned, we firstly identify the firms that cooperate exclusively with same-group internationally and, if it is the case, also nationally (international same group only). Then, we build a set of variables controlling for whether the firms were collaborating only with one type of external partner internationally and, if it is the case, also nationally: international vertical only, international horizontal only, and international institutional only. In addition, we introduce the variable international multi-partners, which is equal to 1 if the firm is collaborating with at least two different external partners, at least one of which is located abroad. Finally, although we are not interested to isolate the effects of same-group cooperation, we introduce a control that accounts for both national only same group only and international same group only, namely those firms that collaborate only with firms from the same group (internationally, and/or nationally) (same group only) [9].

As long as the intertemporal dimension is concerned, we construct the variable continuity which counts the number of years of cooperative behaviour up to t-1 (Nieto and Santamaría, 2007). We also create three dummy variables, indicating whether the firm declares R&D collaboration in t-1 and before the crisis (in 2004-2008) (persistent cooperation), only during (during crisis cooperation) but not before, and only before the crisis but not during (before crisis cooperation).

For the second-stage step, additional controls are size, its square term and market share (Raymond et al., 2010; Vega-Jurado et al., 2009; Veugelers and Cassiman, 1999). In addition, we introduce the share of internal R&D expenditures over total sales (in-house R&D intensity) as a proxy for a firm's absorptive capacity (Becker and Dietz, 2004), foreign ownership (Nieto and Santamaría, 2010), whether the firm conducted internal R&D activities continuously (permanent R&D) (Raymond et al., 2010), the degree of openness (Laursen and Salter, 2006), the importance of demand-pull factors

[9] At the geographical level, we do not distinguish between collaboration with same-group firms or external, since we are interested in the capacity of firm to undertake relations at different geographical level. Hence, if they have collaboration agreements with foreign units of the same corporate company, the firms are exposed to the same benefits as from an external partner located abroad. A different approach has been followed for the organizational dimension. The cooperation with the same-group firms and the one with partners that are external to the corporate group implies very different coordination mechanisms, hence they cannot be placed on the same level. Therefore, the cases when firms cooperate with a single type of national external partners and with same-group firms at national level only cannot be consider a multi-partnership, and they have been included in the categories national only vertical only, national only horizontal only, and national only institutional only. Similarly, the cases when firms cooperate with a single type of national external partners and with same-group firms at international level cannot be consider a case of multi-partnership, neither exclusively nationally nor internationally, and they have been included in the categories national only vertical only, national only horizontal and national only institutional only.

(Raymond et al., 2010), the international market scope as declared by firms (Cassiman and Veugelers, 2006; Nieto and Santamaría, 2007), and whether it was a new firm in 2004 (Archibugi et al., 2013b). A set of 2-digit industry dummies is introduced.

The appendix provides the correlation matrix of the variables used in the second-stage equation (Table A1) in the unbalanced panel.

4 Descriptive analysis

What began as a financial crisis quickly morphed into a crisis in the real economy in late 2008, when many countries around the world start to slump into recession (Keeley and Love, 2010). Similarly to Hud and Hussinger (2014) for Germany, we consider 2009 as the year of the beginning of the crisis, since 2009 is the first year with negative GDP growth in Spain, which returns to positive in 2014 (European Commission, 2015).

Table 1 provides an overview on the cooperation and innovation behaviour of firms in selected years. The total sample of firms based on our selection decreases over years. It ranges from 8438 firms in 2004 to 7510 in 2012, with a peak of 9705 in 2006. The number of innovative firms (i.e. which have product or/and process, and/or ongoing innovation) and cooperative innovative firms follow this trend. However, if we consider the shares of these two groups of firms, some differences emerge. The share of innovative firms on total sample firms is higher before the crisis than after. In 2008, the innovative firms were 6925 (i.e. 76.07% of total sample firms); in 2010 they were 6344 and in 2012 they dropped to 4991, which account respectively for 76.78% and 66.46% of total sample firms. Similarly, the cooperative innovative firms, after a decreasing trend up to 2008 (i.e. from 37.77% in 2004 to 34.89% in 2008), this share increases during the crisis, up to 41.68% in 2012. Hence, despite both the absolute number of innovative and cooperative innovative firms, following the general pattern, have declined during the crisis, the ratio of cooperative innovative has actually increased, which signals that cooperative innovative firms have decreased at a slower pace than innovative.

[TABLE 1 ABOUT HERE]

Table 2 shows the number and share on total cooperative innovative firms by geography and type of partners in selected years. The share of national only cooperative innovative firms decreased since 2006 in favour of firms doing only or also international agreements. However, exclusive national cooperation constitutes the majority (i.e. 61.79% in 2004 and 59.42% in 2012), while having at least an international partner account for 32.21% in 2004 and 40.57% in 2012.

The distribution of firms across types of partners reflects that roughly half of firms have multi-partner strategies and that this trend is increasing. In terms of share, it goes from 43.21% in 2004 to 50.29% in 2012. Among single-partner firms, firms collaborating only with institutions exhibit the highest percentage, with a decreasing trend during the crisis, from 29.45% in 2004 to 20.72% in 2012. Firms collaborating only with vertical partners are the second largest group, which shows a quite stable trend, from 17.09% in 2004 to 17.26% in 2012, except for a peak of 20.46% in 2006. As third largest group, there are the firms collaborating with same-group firms, with an increasing trend. Finally, collaboration with competitors is the least frequent, and with a decreasing trend.

By looking at the distribution across geography and partners, the patterns of firms collaborating exclusively with one type of partners are reproduced also at national and international level. For example, national only vertical only is quite stable across years, and it constitutes 12.36% in 2004 and 12.93% in 2012, and international vertical only firms change slightly as well, from 4.73% in 2004 to 4.33% in 2012. Similarly, the multi-partner categories are among the largest group; in 2004, national only multi-partners accounts for 19.02% and international multi-partners for 24.19%, while in 2012 they account for 21.92% and 28.37%, respectively, both with increasing trends. Interestingly, the national institution only firms are among the most frequent category; in 2004, firms collaborating exclusively with national institutions were 24.93%, even higher than national only multi-partners, but it dropped to 18.94% in 2012 (i.e. the third largest category). These figures show that cooperative innovative firms purse a diversified strategy, both at national and international level, which has been reinforced during the crisis. Conversely, external institutional alliances at the national level (which is a peculiar trait of Spanish NSI) (Belderbos et al., 2015) seems to lose ground during the crisis, probably for the reduction of public funding for incentivizing firms to maintain cooperation agreements with university and research centres.

[TABLE 2 ABOUT HERE]

In Table 3, we use the balanced panel and compare the innovation performance for innovative, cooperative innovative and non-cooperative innovative firms in three different time frames (whole period, pre-crisis period, and during-crisis period)[10], and with three different measures of innovation performance: the share of sales from new products, the share of sales from products new to the firm (new incremental-innovative

[10] These time frames reflect the pre- and during-crisis periods considered in the estimations, as discussed in Section 3.2.

products), and the share of sales from products new to the market (new radical-innovative products). Cooperative innovative firms have a higher innovation performance than non-cooperative innovative firms, and this holds true both across time frames and across different measures of innovation performances. The innovation performance has decreased during the crisis for all categories of firms and measures of innovation performances; this suggests that on average the crisis has affected innovation outputs of all firms. However, it seems that the share of sales from new radical-innovative products was hit from the crisis to a lesser extent; indeed, overall mean of innovation performance of cooperative innovative firms in the pre-crisis is 13.12% while during the crisis is 12.59%, namely about 0.5 points of change, the lowest variation across the different categories of firms and measures of innovation performances between pre- and during-crisis figures.

[TABLE 3 ABOUT HERE]

Table 4 shows the innovation performance of cooperative innovative firms which had R&D cooperation for the first time during the crisis, and cooperative innovative firms which undertook R&D cooperation only before the crisis[11], for the balanced panel. The figures are shown in the three time frames, and with three different measures of innovation performance, similarly than in Table 3. The overall mean of innovation performance is systematically lower during the crisis than before for both categories of firms and for the three measures of innovation performance. The decrease is less prominent for first-time cooperative firms in the crisis, suggesting that the most recent cooperation behaviour during the turbulent time is more important than remote cooperation in expansion periods, and more strongly in the case of producing new radical-innovative products.

[TABLE 4 ABOUT HERE]

5 Econometric results

We firstly estimate the selection equation (the propensity to invest in innovation) for each year. Table A2 in the Appendix presents the results. From these estimations, we obtain the inverse Mill's ratio which are subsequently included in the second stage. Inverse Mill's ratios account for the selection bias caused by the fact that we only observe the innovation performance of firms that made an innovation investment.

[11] To keep overlapping years to the lowest, we do not consider 2009.

Table 5 shows the estimation results of the second-stage model. For the whole period, we estimate the unbalanced panel where the dependent variable is the share of sales from new incremental-innovative products (model 1) and new radical-innovative products (model 2). The variable of interest cooperation is positive on both specifications, although statistically significant ($p < 0.01$) only for the radical innovation performance (model 2). In line with previous studies suggesting that R&D cooperation has a more important impact on highly innovative products (Nieto and Santamaría, 2007), we find that external technological collaboration has a considerable positive impact on the share of sales due to products new to the market, while such innovation strategy is negligible for the shares of sales due to products new to the firm. A possible reason for these different results is that in order to outweigh the costs of accessing to external knowledge not available inside the firms or through other means, such as knowledge spillovers or purchase of R&D services, the firms expect that the technological cooperation brings to breakthrough innovation. Accordingly, other sources of knowledge may be relevant for boosting the innovation sales of new incremental-innovative products. This empirical result is also in line with the idea that R&D cooperation is an explorative strategy that has more to do with discovering and risk-taking that would ensure some long-term returns (more likely in the case of radical innovation), and less to do with the mere reception of innovative products already present in the market which, although spurring innovation sales for those products, are not necessarily the results of an explorative strategy. For these reasons, we restrict our subsequent empirical analyses on the share of sales from new radical-innovative products.

Model 3 in Table 5 shows the balanced panel[12] for radical innovation performance. For the pre-crisis years and the during-crisis years, we run only the balanced panel (model 4 and 5, respectively). As for model 2, cooperation is positive and significant at $p < 0.01$ in all three specifications of the balanced panel. For the whole period, the coefficient is slightly higher for the unbalanced panel (model 2) than the balanced (model 3). All the remaining controls are statistically significant and show the expected sign in the unbalanced panel, while some of these variable lose their significance in the balanced panel. In-house R&D intensity is positively correlated to innovation performance (Belderbos et al., 2015; Nieto and Santamaría, 2007). Size is negative and its squared term

[12] We run the balanced model to have the same firms before and after the crisis, and therefore we ensure comparability between the two estimations.

is positive, thus suggesting a non-linear relation between size and performance (Badillo and Moreno, 2015; Cassiman and Veugelers, 2006). Firms that have carried out R&D continuously (permanent R&D) have better performance, as they have accumulated knowledge and implemented learning processes (Badillo and Moreno, 2015). Belonging to a foreign multinational has a positive effect on performance, suggesting that internationalization could help the firms to increase the relative sales of their innovative products (Belderbos et al., 2015; Duysters and Lokshin, 2011). This variable is not significant for the subsample of firms that are present all years (model 3). In line with previous studies, the degree of openness of the firm and the demand-pull control have a positive impact on innovation performance (Belderbos et al., 2015; Duysters and Lokshin, 2011). In line with studies that detect the importance of export, the variable accounting for whether the firm serves international market is positive (Nieto and Santamaría, 2007), which reinforces the idea that internationalization boosts innovation productivity. The fact that the firm has been newly established in 2004 positively affect innovation sales, but this control is not significant in the balanced panel, suggesting that survival innovative firms are long-established organizations. Finally, market share is also positive, suggesting that having a strong market position helps the firms to increase the benefits of their innovation efforts, as for example in terms of long-standing routines and competencies to manage the transition from ideas to market (Rothaermel and Deeds, 2004).

Taking into account the crisis (model 4-5), during the crisis the coefficient is three times larger than in the pre-crisis years. Size, foreign, and market share are significant before the crisis but not during. We run a test of comparison of cooperation coefficients for the balanced panel across the two time frames. As reported in the last row in Table 5, the test rejects the null hypothesis of equality at $p < 0.01$. Hence, having cooperation agreements positively affects the innovation performance of Spanish firms during the crisis to a greater extent than before the crisis, suggesting that an explorative strategy increases the flows of knowledge not available inside the firms and that this external source of knowledge offers a way to increase sales from radical-innovative products during turbulent times.

[TABLE 5 ABOUT HERE]

We now turn to explore the different impacts of cooperation before and during the crisis by geographical locations of partners. Table 6 shows the estimations for the whole period with both the unbalanced panel (model 6) and balanced panel (model 7), for the

pre-crisis years (model 8) and the during-crisis years (model 9) for the balanced panel. In line with previous studies (Badillo and Moreno, 2015), both national only and international are positive and significant at $p < 0.01$ in the whole-period models. When we focus on the difference between the two periods, national only cooperation is unimportant before the crisis (the coefficient is small and non-significant), while it turns significant and larger during the crisis. Instead, the coefficient of international cooperation is significant both before and during the crisis, and larger during the crisis. The comparison tests reported in the bottom row in Table 6 show that these differences across periods are statistically significant for both national only and international (at $p < 0.01$). These results suggest that during the crisis firms have implemented an exploratory strategy in any direction that is having a beneficial influence on their innovative outcomes. While firms did not rely on national cooperation to boost innovation performance before the crisis, during the crisis they received some benefits from such exploratory strategy, even if confined to national borders. However, a comparison between the coefficients of national only and international during the crisis (model 9) points out that the benefits from collaborating with foreign partners are higher, as the impact of international alliances is almost double the size of exclusively national cooperation.

[TABLE 6 ABOUT HERE]

We report the estimates on the impact of cooperation by geography and partners in Table 7, for the whole period with both the unbalanced panel (model 10) and balanced panel (model 11), and for the pre-crisis years (model 12) and the during-crisis years (model 13) for the balanced panel. In terms of the differences between models 10 and 11, a number of coefficients are positive and significant in both specifications, with the exception of same group only, foreign and new firm which are significant only in the unbalanced whole-period model. As far as the before- and during-crisis periods are concerned (models 12-13), the cooperation coefficients that are positive and significant in both periods are systematically higher during the crisis than before (i.e. national only multi-partners, international vertical only, and international multi-players). In addition, some cooperation coefficients increase magnitude and significance during the crisis (i.e. national only vertical only, national only institutional only, and international institutional only). The bottom rows in Table 7 show the tests of comparison for the cooperation variables, which suggest that all the above-mentioned increases of the coefficients in the during-crisis years are statistically significantly higher than before the crisis, with the

exception of international vertical only. In particular, the tests for the multi-partner variables reject the null hypothesis of the equality of coefficients before and during the crisis, both at the national ($p < 0.05$) and international ($p < 0.01$) level. This suggests that relying on multiple types of sources is beneficial to firms, especially if these partners are also international. In this case, firms could benefit from the combination of organizational and geographical diversity, as they are able to access to specialized knowledge of different partners, as well as to different knowledge-base of foreign NSI of their partners. The coefficient of national only institutional only, which is positive and statistically significant during the crisis ($p < 0.01$) and not before, is marginally significant in the comparison test ($p < 0.10$). Not surprisingly it is the result for the test of the coefficient of international institutional only ($p < 0.01$), which in the estimates turns from slightly significant and negative ($p < 0.10$) before the crisis to positive and significant at $p < 0.05$ during the crisis. These results suggest that the firms which successfully managed to access to institutional partners received remarkable benefits, even though this was the only type of partners, either only nationally or internationally. For international vertical only, which was positive and significant before and during the crisis, the test fails to detect a statistically significant difference in the two periods, while the test for the coefficient of national vertical only is significant ($p < 0.05$), although being positive and significant only in the during-crisis estimations. These results about vertical partners point out that value-chain connections (i.e. clients and suppliers) are always important sources of knowledge for innovative products at the international level regardless the business cycle; instead, at the national level these collaborations are particularly important during a crisis, suggesting that in turbulent periods the vertical linkages, even if it is the only cooperation, turns out to pay off also within the national borders. Finally, for horizontal cooperation, for which the coefficients are not significant in models 12-13, the comparison test suggests a possible increase in importance of the international cooperation during the crisis.

[TABLE 7 ABOUT HERE]

Finally, we estimate how past experience in R&D cooperation helps the firms to face the crisis. Table 8 shows the estimations for the balanced panel during crisis, in which we introduced a variable for continuity in R&D collaboration (continuity) that accounts for the total years of collaboration up to t-1 (model 14). The coefficient is positive and significant at $p < 0.01$, suggesting that cumulative past experience determines the current innovation performance of firms during the crisis (Nieto and Santamaría, 2007). To

explicitly test whether the most recent R&D cooperation matters more than remote alliances, and whether the combination of cooperative behaviour under different business climates increases innovation performance during recession, model 15 in Table 8 shows the estimation in which we introduced three dummy variables accounting for whether the firm has collaborated only in t-1 (during-crisis cooperation), or only before (before-crisis cooperation), or both in t-1 and before 2008 (persistent cooperation). Results show that newly-cooperative firms in the recession perform well (coefficient is positive and significant at $p < 0.01$), while experience in the expansion period does not have a statistically significant effect on innovation performance during the crisis, which reinforces the idea that what matters is the most recent cooperation behaviour. However, a combination of past experience in the current business climate and in the previous expansion period (persistent cooperation is significant at $p < 0.01$) exhibits a higher coefficient than that of the during-crisis cooperation, which signals that the combination of past acquired knowledge and current external knowledge boosts innovation performance during recessions. Indeed, the recent experience offers the most valuable knowledge, but the firms that have followed an explorative strategy under different business climates gain from knowledge diversity. The external knowledge acquired during a certain period become part of the current knowledge stock of firms, hence the combination of past and current external knowledge inspires new innovative ideas (Kogut and Zander, 1992) and leads to higher innovation performance than in the case of cooperative agreements undertaken only before or only during the crisis.

[TABLE 8 ABOUT HERE]

6 Conclusions

During the recent economic recession, firms have been less willing to invest in innovation. Technological collaboration has followed a similar pattern, as the absolute number of cooperating firms has decreased during the crisis; at the same time, a group of firms managed to conduct R&D alliances during the crisis. In this study, we have investigated how the last economic recession has changed the impact of R&D collaboration on innovation performance.

Our findings point out that R&D cooperation has been a successful strategy to boost innovation performance during the last recession, as it is a way to access to different, new or complementary resources that may lack in-house. As far as the geographical dimension is concerned, we find an increased relevance of the impact of national R&D cooperation

in an economic turmoil, suggesting that that during a crisis firms are searching for external knowledge in any direction, irrespectively of the geographical locations. In line with previous studies, in any period considered, international R&D cooperation has higher impact than national, as international partners provide access to heterogeneous sources of knowledge and to frontier-technological inputs (Duysters and Lokshin, 2011).

Regarding the organizational dimension, we find that when the firm cooperates with a variety of partners (organizational diversity), there is outstanding evidence of a stronger effect on innovation performance during the crisis than before. This effect is magnified when the diversity is at the maximum, i.e. when the variety of partners includes at least an international tie. In addition, we find that having only institutional partners turns more important during the crisis, either only nationally or internationally, which reinforces the importance of research organizations to support firms, especially during turbulent times. We also find that the exclusive cooperation with international vertical partners has always a strong effect; instead, at the national level vertical cooperation has a higher payoff during the crisis than before, suggesting that this exploration strategy in any direction is beneficial, even if it is the only type.

Finally, we find that continuity in R&D cooperation has a positive impact on innovation performance (Belderbos et al., 2015; Nieto and Santamaría, 2007) and the combinative capabilities resulting from firms collaborating in different business climate have the highest impact on innovation performance.

Table 1 – Number and share of firms by innovation and cooperation behaviour in selected years.

	2004		2006		2008		2010		2012	
	#	Share	#	Share	#	Share	#	Share	#	Share
Innovative firms*	6042	71.60	7647	78.79	6925	76.07	6344	76.78	4991	66.46
Non-innovative	2396	28.40	2058	21.21	2178	23.93	1919	23.22	2519	33.54
Total	**8438**	**100**	**9705**	**100**	**9103**	**100**	**8263**	**100**	**7510**	**100**
Cooperative innovative	2282	37.77	2703	35.35	2416	34.89	2289	36.08	2080	41.68
Non-cooperative innovative	3753	62.12	4944	64.65	4509	65.11	4055	63.92	2911	58.32
Not answered	7	0.12	0	0	0	0	0	0	0	0
Total	**6042**	**100**	**7647**	**100**	**6925**	**100**	**6344**	**100**	**4991**	**100**

* which have product or/and process, and/or ongoing innovation

Table 2 – Number and share of cooperative innovative firms by geographical location of partners and type of partners.

	2004		2006		2008		2010		2012	
	#	Share	#	Share	#	Share	#	Share	#	Share
Geography										
National only	1410	61.79	1772	65.56	1526	63.16	1391	60.77	1236	59.42
International	872	38.21	931	34.44	890	36.84	898	39.23	844	40.58
Total	**2282**	**100**	**2703**	**100**	**2416**	**100**	**2289**	**100**	**2080**	**100**
Partners										
Same group only	150	6.57	154	5.70	125	5.17	97	4.24	188	9.04
Vertical only	390	17.09	553	20.46	425	17.59	401	17.52	359	17.26
Horizontal only	84	3.68	82	3.03	70	2.90	63	2.75	56	2.69
Institutional only	672	29.45	780	28.86	681	28.19	606	26.47	431	20.72
Multi-partners	986	43.21	1134	41.95	1115	46.15	1122	49.02	1046	50.29
Total	**2282**	**100**	**2703**	**100**	**2416**	**100**	**2289**	**100**	**2080**	**100**
Geography and partners										
National only same group only	98	4.29	102	3.77	70	2.90	53	2.32	112	5.38
National only vertical only	282	12.36	434	16.06	318	13.16	289	12.63	269	12.93
National only horizontal only	67	2.94	67	2.48	57	2.36	50	2.18	47	2.26
National only institution only	569	24.93	721	26.67	636	26.32	555	24.25	394	18.94
National only multi-partners	434	19.02	502	18.57	497	20.57	487	21.28	456	21.92
International same group only	52	2.28	52	1.92	55	2.28	44	1.92	76	3.65
International vertical only	108	4.73	119	4.40	107	4.43	112	4.89	90	4.33
International horizontal only	17	0.74	15	0.55	13	0.54	13	0.57	9	0.43
International institution only	103	4.51	59	2.18	45	1.86	51	2.23	37	1.78
International multi-partners	552	24.19	632	23.38	618	25.58	635	27.74	590	28.37
Total	**2282**	**100**	**2703**	**100**	**2416**	**100**	**2289**	**100**	**2080**	**100**

Table 3 – Descriptive statistics of the share of sales from new products by periods (balanced panel)

	Whole period (2005-2013)				Pre-crisis (2005-2010)				During-crisis (2011-2013)			
	Overall Mean	Between SD	Within SD	Median	Overall Mean	Between SD	Within SD	Median	Overall Mean	Between SD	Within SD	Median
	New products											
Innovative firms	26.32	24.84	26.56	9.00	27.09	27.42	23.76	10	24.53	29.99	19.29	5
Cooperative innovative	28.94	29.71	23.29	11.30	29.57	30.91	20.61	13	27.65	32.55	16.11	10
Non-cooperative innovative	24.77	27.47	25.36	5.00	25.71	29.86	22.5	5	22.44	31.18	18.16	2
	New incremental-innovative products											
Innovative firms	15.66	18.82	21.82	1.00	16.04	20.88	19.65	1	14.78	23.29	16	0
Cooperative innovative	15.99	22.67	18.49	3.00	16.44	23.16	16.93	4.2	15.06	24.74	12.21	2
Non-cooperative innovative	15.47	21.29	21.27	0.00	15.82	23.22	18.81	0.1	14.59	24.79	15.74	0
	New radical-innovative products											
Innovative firms	10.65	15.21	17.29	0.00	11.04	16.94	15.9	0	9.75	18.65	12.35	0
Cooperative innovative	12.95	19.27	16.56	0.10	13.12	20.61	14.78	0.5	12.59	21.43	11.98	0
Non-cooperative innovative	9.30	16.75	15.83	0.00	9.88	18.45	14.52	0	7.84	18.71	10.68	0

Table 4 – Description of the share of sales of new products of first-time cooperative innovative firms in the during/post-crisis period and cooperative innovative firms only before crisis, by periods (balanced panel).

	Whole period (2005-2013)				Pre-crisis (2005-2010)				During-crisis (2011-2013)			
	Overall Mean	Between SD	Within SD	Median	Overall Mean	Between SD	Within SD	Median	Overall Mean	Between SD	Within SD	Median
						New products						
First-time cooperative innovative in 2010-2013 (# 575)	25.00	22.74	27.41		25.40	26.38	23.86		24.21	30.07	20.24	
Cooperative innovative in 2004-2008, not afterwards (#865)	25.91	25.07	26.91		27.24	27.79	24.36		22.40	30.37	18.81	
						New incremental-innovative products						
First-time cooperative innovative in 2010-2013 (# 575)	14.8	17.56	22.03		15.09	20.76	19.14		14.239	23.28	16.35	
Cooperative innovative in 2004-2008, not afterwards (#865)	16.32	19.98	22.7		16.81	21.76	20.6		15.05	24.97	16.72	
						New radical-innovative products						
First-time cooperative innovative in 2010-2013 (# 575)	10.195	14.18	18.05		10.3	16.74	15.84		9.97	18.35	13.92	
Cooperative innovative in 2004-2008, not afterwards (#865)	9.58	14.82	17.07		10.43	16.71	16.18		7.33	18.33	10.48	

Table 5 – The impact of R&D cooperation on innovation performance

DV: Innovation sales	(1) Whole period (unbalanced) Incremental	(2) Whole period (unbalanced) Radical	(3) Whole period (balanced) Radical	(4) Pre-crisis (balanced) Radical	(5) During-crisis (balanced) Radical
cooperation	0.080	0.478***	0.401***	0.233***	0.737***
	(0.065)	(0.060)	(0.058)	(0.080)	(0.114)
in-house R&D intensity	0.502***	1.702***	2.609***	2.588***	2.658***
	(0.187)	(0.190)	(0.310)	(0.386)	(0.486)
size	0.160	-0.569***	-0.660***	-0.768***	-0.358
	(0.115)	(0.103)	(0.120)	(0.155)	(0.226)
size 2	-0.011	0.055***	0.067***	0.073***	0.049**
	(0.011)	(0.010)	(0.012)	(0.015)	(0.021)
permanent R&D	0.200***	1.156***	1.193***	1.186***	1.200***
	(0.076)	(0.065)	(0.067)	(0.089)	(0.113)
foreign	-0.243**	0.153**	0.135	0.191*	0.008
	(0.096)	(0.075)	(0.086)	(0.106)	(0.126)
openness	0.102***	0.098***	0.101***	0.107***	0.092***
	(0.014)	(0.012)	(0.014)	(0.018)	(0.021)
demand-pull	0.804***	1.174***	1.126***	1.177***	1.067***
	(0.080)	(0.066)	(0.073)	(0.084)	(0.132)
international market	0.074	0.319***	0.318***	0.309***	0.400***
	(0.089)	(0.076)	(0.091)	(0.113)	(0.151)
new firm	0.697***	0.377**	0.177	0.065	0.372
	(0.201)	(0.186)	(0.252)	(0.301)	(0.399)
market share	-3.122***	2.560**	2.783**	3.825**	2.787
	(1.126)	(1.081)	(1.131)	(1.620)	(1.766)
Constant	-2.461***	-5.483***	-5.773***	-4.975***	-10.375***
	(0.883)	(1.073)	(1.183)	(1.515)	(0.926)
Observations	28,897	28,897	22,267	14,554	7,713
R-squared	0.034	0.092	0.093	0.090	0.105
Comparison test (balanced)[a]					
Cooperation	$\beta_{2005\text{-}2010}=\beta_{2011\text{-}2013}$: $\chi 2=16.04$***				

Bootstrapped (1750 reps) standard errors in parentheses; industry dummies, inverse mills ratio and means-fixed effects are included. *** p<0.01, ** p<0.05, * p<0.1 n.s. non-significant

[a] Wald test on equality of coefficients in pooled estimations

Table 6 – R&D cooperation by geography

DV: Radical innovation sales	(6) Whole period (unbalanced)	(7) Whole period (balanced)	(8) Pre-crisis (balanced)	(9) During-crisis (balanced)
national only	0.322***	0.265***	0.137	0.536***
	(0.065)	(0.078)	(0.095)	(0.121)
international	0.737***	0.624***	0.397***	1.041***
	(0.074)	(0.084)	(0.102)	(0.157)
in-house R&D intensity	1.642***	2.512***	2.516***	2.520***
	(0.199)	(0.299)	(0.368)	(0.573)
size	-0.581***	-0.669***	-0.775***	-0.369
	(0.108)	(0.125)	(0.156)	(0.243)
size 2	0.055***	0.067***	0.073***	0.049**
	(0.010)	(0.012)	(0.016)	(0.024)
permanent R&D	1.145***	1.184***	1.179***	1.188***
	(0.065)	(0.072)	(0.083)	(0.112)
foreign	0.095	0.083	0.153	-0.062
	(0.078)	(0.086)	(0.120)	(0.129)
openness	0.096***	0.098***	0.105***	0.087***
	(0.013)	(0.013)	(0.018)	(0.023)
demand-pull	1.163***	1.116***	1.173***	1.039***
	(0.061)	(0.070)	(0.084)	(0.139)
international market	0.300***	0.301***	0.298***	0.370**
	(0.081)	(0.088)	(0.113)	(0.156)
new firm	0.363*	0.171	0.064	0.352
	(0.196)	(0.251)	(0.305)	(0.400)
market share	2.374**	2.657**	3.689**	2.640
	(1.181)	(1.177)	(1.627)	(1.771)
Constant	-5.214***	-5.548***	-4.865***	-10.227***
	(1.067)	(1.105)	(1.557)	(0.875)
Observations	28,897	22,267	14,554	7,713
R-squared	0.092	0.094	0.091	0.107
Comparison test[a]				
national only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: $\chi 2 = 7.96$***			
international	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: $\chi 2 = 15.13$***			

Bootstrapped (1750 reps.) standard errors in parentheses; industry dummies, inverse mills ratio and means-fixed effects are included. *** p<0.01, ** p<0.05, * p<0.1 n.s. non-significant

[a] Wald test on equality of coefficients in pooled estimations

Table 7– R&D cooperation by geography and type of partners

DV: Radical innovation sales	(10) Whole period (unbalanced)	(11) Whole period (balanced)	(12) Pre-crisis (balanced)	(13) During-crisis (balanced)
national only vertical only	0.001	0.108	-0.111	0.533**
	(0.114)	(0.124)	(0.152)	(0.234)
national only horizontal only	-0.211	-0.137	0.182	-0.548
	(0.232)	(0.277)	(0.379)	(0.381)
national only institutional only	0.332***	0.305***	0.171	0.559***
	(0.081)	(0.102)	(0.127)	(0.167)
national only multi-partners	0.617***	0.455***	0.284**	0.803***
	(0.100)	(0.116)	(0.120)	(0.187)
international vertical only	0.691***	0.716***	0.535**	1.020***
	(0.170)	(0.230)	(0.262)	(0.334)
international horizontal only	0.225	0.007	-0.653	1.620
	(0.559)	(0.599)	(0.706)	(1.029)
international institutional only	0.021	-0.001	-0.544*	1.101**
	(0.245)	(0.289)	(0.327)	(0.517)
international multi-partners	0.826***	0.698***	0.488***	1.096***
	(0.087)	(0.099)	(0.123)	(0.160)
same group only	0.437**	0.132	0.205	0.123
	(0.184)	(0.196)	(0.265)	(0.303)
in-house R&D intensity	1.617***	2.499***	2.520***	2.484***
	(0.204)	(0.289)	(0.399)	(0.488)
size	-0.570***	-0.656***	-0.758***	-0.353*
	(0.092)	(0.128)	(0.155)	(0.213)
size 2	0.054***	0.066***	0.071***	0.047**
	(0.009)	(0.013)	(0.015)	(0.021)
permanent R&D	1.131***	1.172***	1.169***	1.167***
	(0.063)	(0.074)	(0.086)	(0.116)
foreign	0.145*	0.134	0.179*	0.030
	(0.074)	(0.092)	(0.104)	(0.143)
openness	0.090***	0.094***	0.102***	0.081***
	(0.013)	(0.013)	(0.016)	(0.026)
demand-pull	1.160***	1.113***	1.167***	1.039***
	(0.061)	(0.071)	(0.088)	(0.129)
international market	0.295***	0.298***	0.297***	0.368**
	(0.077)	(0.102)	(0.112)	(0.171)
new firm	0.355*	0.167	0.060	0.343
	(0.205)	(0.233)	(0.308)	(0.389)
market share	2.348**	2.644**	3.653**	2.676
	(1.129)	(1.142)	(1.821)	(1.733)
Constant	-5.136***	-5.459***	-4.856***	-10.209***
	(1.273)	(1.205)	(1.582)	(0.799)
Observations	28,897	22,267	14,554	7,713
R-squared	0.093	0.094	0.091	0.108
Comparison test[a]				
national only vertical only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=5.35$***			
national only horizontal only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=1.76$ n.s.*			
national only institutional only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=3.29$**			
national only multipartners	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=5.24$***			
international vertical only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=1.25$ n.s.*			
international horizontal only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=2.93$**			
international institutional only	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: $\chi2=6.94$***			
international multipartners	$\beta_{2005\text{-}2010} = \beta_{2011\text{-}2013}$: *$\chi2=10.30$****			

Bootstrapped (2500reps) standard errors in parentheses; industry dummies, inverse mills ratio and means-fixed effects are included.*** p<0.01, ** p<0.05, * p<0.1 , n.s. non-significant.

[a] Wald test on equality of coefficients in pooled estimations

Table 8 – The impact of experience in R&D cooperation on innovation performance in the during-crisis period (2011-13), balanced panel

DV: Radical innovation sales	(14) During-crisis (balanced)	(15) During-crisis (balanced)
continuity	0.096***	
	(0.017)	
during-crisis cooperation		0.660***
		(0.184)
before-crisis cooperation		0.233
		(0.148)
persistent cooperation		1.013***
		(0.145)
in-house R&D intensity	1.978***	2.536***
	(0.315)	(0.378)
size	-0.275	-0.514***
	(0.169)	(0.198)
size 2	0.038**	0.064***
	(0.017)	(0.019)
permanent R&D	1.162***	1.132***
	(0.104)	(0.113)
foreign	0.063	0.023
	(0.129)	(0.139)
openness	0.104***	0.102***
	(0.021)	(0.025)
demand-pull	1.085***	1.105***
	(0.113)	(0.130)
international market	0.274*	0.112
	(0.153)	(0.168)
new firm	0.501*	0.430
	(0.274)	(0.322)
market share	3.785*	2.562
	(1.974)	(1.810)
Constant	-5.463***	-6.619***
	(1.320)	(2.120)
Observations	9,010	8,144
R-squared	0.097	0.112

Bootstrapped standard errors in parentheses; industry dummies, inverse mills ratio and means-fixed effects are included. *** p<0.01, ** p<0.05, * p<0.1

Appendix

A1 – Correlation table (unbalanced panel)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	cooperation	1													
2	national only	0.720***	1												
3	international	0.521***	-0.152***	1											
4	national only vertical only	0.299***	0.397***	-0.027***	1										
5	national only horizontal only	0.126***	0.178***	-0.023***	-0.016***	1									
6	national only institutional only	0.417***	0.562***	-0.052***	-0.052***	-0.022***	1								
7	national only multi-partners	0.375***	0.534***	-0.081***	-0.047***	-0.020***	-0.065***	1							
8	international vertical only	0.170***	-0.050***	0.331***	-0.021***	-0.009**	-0.030***	-0.027***	1						
9	international horizontal only	0.058***	-0.017***	0.114***	-0.007**	-0.003	-0.010***	-0.009**	-0.004	1					
10	international institutional only	0.123***	-0.036***	0.240***	-0.015***	-0.006*	-0.021***	-0.019***	-0.009**	-0.003	1				
11	international multi-partners	0.422***	-0.124***	0.814***	-0.053***	-0.022***	-0.073***	-0.066***	-0.030***	-0.010***	-0.022***	1			
12	same group only	0.195***	0.146***	0.124***	-0.024***	-0.010***	-0.034***	-0.031***	-0.014***	-0.004	-0.010***	-0.034***	1		
13	continuity	0.620***	0.414***	0.432***	0.147***	0.055***	0.241***	0.269***	0.109***	0.030***	0.075***	0.391***	0.102***	1	
14	persistent cooperation	0.952***	0.681***	0.515***	0.274***	0.121***	0.403***	0.360***	0.161***	0.052***	0.122***	0.424***	0.176***	0.636***	1

[cont.]

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
15	after crisis cooperation	0.190 ***	0.175 ***	0.064 ***	0.106 ***	0.029 ***	0.078 ***	0.075 ***	0.048 ***	0.030 ***	0.011 ***	0.026 ***	0.081 ***	0.010 **	-0.101 ***	1											
16	before crisis cooperation	-0.47 ***	-0.286 ***	-0.208 ***	-0.119 ***	-0.050 ***	-0.166 ***	-0.149 ***	-0.068 ***	-0.023 ***	-0.049 ***	-0.168 ***	-0.078 ***	0.032 ***	-0.378 ***	-0.078 ***	1										
17	in-house R&D intensity	0.151 ***	0.075 ***	0.191 ***	-0.007 **	0.004	0.038 ***	0.085 ***	-0.007 **	0.007 **	0.043 ***	0.220 ***	-0.008 **	0.182 ***	0.183 ***	-0.003	-0.029 ***	1									
18	size	0.112 ***	-0.034 ***	0.110 ***	0.007 **	-0.007 **	-0.056 ***	0.002	0.022 ***	-0.010 ***	0.004	0.092 ***	0.058 ***	0.043 ***	0.111 ***	0.030 ***	-0.004	-0.153 ***	1								
19	size 2	0.114 ***	-0.031 ***	0.107 **	0.007 **	-0.005	-0.057 ***	0.007 *	0.021 ***	-0.010 ***	0.002	0.091 ***	0.055 ***	0.042 ***	0.110 ***	0.029 ***	-0.009 **	-0.139 ***	0.981 ***	1							
20	permanent R&D	0.230 ***	0.198 ***	0.280 ***	0.021 ***	0.026 ***	0.132 ***	0.159 ***	0.059 ***	0.030 ***	0.069 ***	0.261 ***	0.026 ***	0.310 ***	0.311 ***	0.011 ***	0.014 ***	0.265 ***	-0.048 ***	-0.056 ***	1						
21	foreign	0.030 ***	-0.076 ***	0.135 *	0.006 *	-0.017 ***	-0.025 ***	-0.052 ***	0.040 ***	-0.005	0.010 ***	0.053 ***	0.097 ***	0.035 ***	0.041 ***	0.013 ***	0.016 ***	-0.063 ***	0.254 ***	0.242 ***	0.003	1					
22	openness	0.229 ***	0.111 ***	0.196 ***	-0.017	0.007	0.055 ***	0.128 ***	0.017 ***	0.008 *	0.023 ***	0.210 ***	-0.004	0.243 ***	0.231 ***	0.017 ***	-0.057 ***	0.091 ***	0.055 ***	0.052 ***	0.220 ***	-0.009 **	1				
23	demand-pull	0.124 ***	0.053 ***	0.106 **	0.011 **	0.007 ***	0.016 ***	0.058 ***	0.032 ***	0.011 **	0.003	0.106 ***	-0.003	0.143 ***	0.119 ***	0.031 ***	-0.042 ***	0.032 ***	-0.024 ***	-0.023 ***	0.126 ***	-0.005	0.263 ***	1			
24	international market	0.055 ***	0.038 ***	0.151 ***	-0.003 *	-0.006 *	0.050 ***	0.021 ***	0.050 **	0.009 **	0.031 ***	0.124 ***	0.029 ***	0.160 ***	0.097 ***	0.023 ***	0.040 ***	-0.007 **	-0.027 ***	-0.056 ***	0.255 ***	0.140 ***	0.098 ***	0.067 ***	1		
25	new firm	0.049 ***	0.026 ***	0.054	0.000	-0.003 ***	0.020 ***	0.016 *	-0.006 *	-0.002 ***	0.014 ***	0.068 ***	0.001	0.071 ***	0.050 ***	-0.007	-0.010 **	0.191 ***	-0.097 ***	-0.085 ***	0.062 ***	-0.031 ***	0.029 ***	0.027 ***	-0.031 ***	1	
26	market share	0.064	-0.005 ***	0.105 ***	0.002	-0.004	-0.019 **	0.008 **	0.026	-0.004	0.005 ***	0.098 ***	0.034 ***	0.075 ***	0.067 ***	0.029 ***	-0.002	-0.031 ***	0.316 ***	0.347 ***	0.044 ***	0.131 ***	0.042 ***	0.011 **	0.058 ***	-0.008 **	1

A2 – Estimation first-stage model (unbalanced panel)

DV: Innovation	Year 2006	Year 2007	Year 2008	Year 2009	Year 2010	Year 2011	Year 2012	Year 2013
Size	-0.035	0.028	0.109**	0.104*	0.081	0.122**	0.204***	0.187***
	(0.551)	(0.608)	(0.043)	(0.065)	(0.157)	(0.034)	(0.001)	(0.002)
Size 2	0.006	-0.004	-0.009	-0.005	-0.002	-0.003	-0.011*	-0.009
	(0.342)	(0.474)	(0.107)	(0.378)	(0.679)	(0.627)	(0.058)	(0.153)
Cost obstacles	0.240***	0.389***	0.401***	0.398***	0.273***	0.211***	0.177***	0.198***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.001)	(0.005)	(0.002)
Market obstacles	0.401***	0.326***	0.225***	0.306***	0.382***	0.376***	0.407***	0.425***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Knowledge obstacles	0.338***	0.297***	0.464***	0.518***	0.360***	0.502***	0.545***	0.567***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Other obstacles	-1.211***	-1.114***	-1.141***	-1.147***	-1.295***	-1.295***	-1.255***	-1.326***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Market share	2.228***	4.677***	8.661***	8.615***	6.937***	4.303***	5.601***	4.540***
	(0.009)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.141***	0.159***	0.169***	0.120***	0.163***	0.172***	0.150***	0.173***
	(0.000)	(0.000)	(0.000)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)
Constant	-0.238	-0.206	-0.576***	-0.682***	-0.570***	-0.882***	-1.157***	-1.180***
	(0.105)	(0.119)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Observations	7,976	9,152	9,075	8,563	8,171	7,795	7,430	7,081
Log L	-4208.29	-4946.04	-5056.18	-4796.21	-4609.41	-4471.40	-4244.33	-4011.50
Pseudo R2	0.20	0.17	0.17	0.17	0.17	0.17	0.17	0.18

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