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The differential impact of open innovation on the efficiency of firms

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Abstract

The effects of open innovation strategies on the economic efficiency of firms is a topic often avoided, and about which little is known. This paper contributes to the exploration of that connection, revealing persistent collaboration and the embeddedness of firms within their environments to be two crucial aspects. Impacts on efficiency are conditioned by the type of external links employed, by the agents with whom a firm collaborates, and by the inherent differences between foreign and domestic firms. Findings obtained from fresh empirical evidence provided in this paper reveal that: 1) collaboration with competitors on innovation generates a direct effect on a firm's efficiency, whether foreign or domestic; 2) only persistent and vertical linkages have a positive impact; and 3) access to complementary sources of knowledge becomes increasingly relevant to a rise in efficiency as a firm increases its embeddedness within a location, making institutional collaboration especially significant for domestic firms.

Keywords: open innovation; collaboration; efficiency of firms; foreign firms; embeddedness

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1. Introduction

Relationships of external collaboration established by firms in order to improve innovation outputs is not a new topic, but has been widely developed in innovation literature (Rosenberg, 1982; von Hippel, 1988; Freeman and Soete, 1997; Tidd, Bessant, and Pavitt, 2000). The interactive character of the innovation process would suggest that innovators rely on external interactions with a variety of agents: other firms that act as customers; suppliers or competitors; and a range of institutions and other agents that are considered relevant sources of knowledge for innovation, such as universities, technological centers, or R&D labs inside innovation systems (von Hippel, 1988; Lundvall, 1992; Brown and Eisenhardt, 1995). According to the evolutionary framework, organizations search out a variety of sources that will allow them to create and combine technologies and knowledge (Nelson and Winter, 1982; Metcalfe, 1994). The success of firms drawing knowledge and expertise from a wide range of external sources gave rise to the 'open innovation' model (Chesbrough, 2003a, 2003b), in which the advantages of firms derived from internal R&D decrease, even as the level of embeddedness within the environment gains importance, along with the capacities of those agents considered helpful in the generation of relevant knowledge. Therefore, the search for and access to external knowledge sources is a determinant aspect that may be understood more as complementary than substitutive (Archibugi and Iammarino, 2002; Chesbrough, 2003; Narula, 2004; Hohberger, *et al*. 2015). The implications from this fact have occupied a central place on agendas in the fields of research, economics, and politics, due to general acceptance of innovation as a driver of competitiveness.

The contributions of this paper to the existing literature are twofold. First, the study directly addresses the effect of open innovation on the economic efficiency of firms; this is done using a methodology relevant to the analysis of the impact on firms' results, based on the 'stochastic production frontier' methodology. Second, we undertake specific treatment of the types of agents with which firms collaborate, explicitly noting the differences between foreign and domestic firms. Our findings confirm that persistent collaboration and the embeddedness of firms represent determinant factors for observing the impact of open innovation on the economic performance of firms.

Most of the literature regarding the evaluation of collaboration and open innovation has been focused on effects on the performance of firms in terms of innovation, aspects of which manifest in a broad spectrum of empirical evidence. However, the effect of collaboration as a dominant strategy toward increasing the economic efficiency of firms has not been very deeply explored, until now. In addition, issues such as the collaboration patterns of foreign firms in a host location, or the indirect effects on firm efficiency, still require greater attention. The absence of a unique explicative model of collaboration for innovation makes difficult any generalization of the conclusions so far obtained, making the generation of fresh empirical work essential to improving understanding on this issue, if potential implications for action are to be derived.

A large number of contributions have focused on the decision to collaborate, and on the discovery and selection of partners, while others analyze the generation of spillover effects (Gulati, 1995; Mowery *et al*., 1998; Cassiman and Veuglers, 2002). Meanwhile, research efforts have been largely devoted to analysis of

the motives for establishing R&D collaboration with partners, and other works have analyzed the impact on the performance of firms. The meta-analysis performed in Pippel (2013) shows that such measures are very heterogeneous. One branch of the existing literature is focused on the impact of collaboration on several measures of innovation performance. A number of papers use the amount of patents granted to firms as a performance measure (Kang and Park, 2012; Baba *et al.,* 2009; Belussi *et al*., 2010; Huang and Yu, 2011). Others take responses by firms to national surveys regarding the successful introduction of innovations as a performance measure, while others try to capture the relative importance of innovations using, for instance, the proportion of turnover due to sales of new products (Kang and Kang, 2010; Un *et al.,* 2010; Gellynck and Vermeire, 2009; Faems *et al.,* 2005; Wu, 2012).

However, "non-innovation"-oriented measures such as the impact on economic performance have been less studied in the available empirical evidence. Only a small group of papers focuses on the impact of collaboration agreements; among these, Belderbos *et al.* (2004; 2015) use labour productivity (the ratio of sales from new products to the number of employees and the growth of labor productivity as valid measures of efficiency. Oerlemans and Meeus (2005) also use labor productivity, along with other indicators linked to innovative performance. On the other hand, Rickne (2006) uses the growth of employment at firms as the relevant indicator. Meanwhile, Colombo *et al.* (2009) use total factor productivity to assess the performance effects of particular international R&D alliances on new technology-based firms.

The implication of the dominant pattern of international firms, increasingly based on global fragmentation of the value chain, is the reconsideration of those factors affecting the innovation strategies of foreign firms, due in part to the increasing importance of real global innovations. The decentralization of strategic activities such as R&D (and others related to innovation in foreign locations) makes relevant the increasing role played by subsidiaries in the development of competitive advantages, as individualized units within a multinational enterprise (MNE) network (Gorg, 2000; Mudambi, 2008; Barlett and Ghoshal, 1986). The direct consequence of this can be that foreign subsidiaries may receive differing mandates, driven by exploitation or by creation strategies directly related to their innovation activities and their deeper embeddedness in foreign contexts (Jarillo and Martínez, 1990; Roth and Morrison, 1992; Birkinshaw, 1996; Cantwell and Mudambi, 2005).

The level of embeddedness of foreign units in their environment may be a key aspect for understanding the role played by external sources of knowledge for innovation on the efficiency differentials between foreign and domestic firms. On the one hand, sporadic external relationships with other agents do not necessarily have the same effect as when broader and deeper strategies dominate – in which case firms tend to be more innovative (Laursen and Salter, 2006; Ahuja, 2000). On the other, there is a direct link between the objectives pursued by firms through collaboration and the selection of collaborators from among different types of partners (Faria, *et al.*, 2010), since this selection may be a determinant aspect for the direct results obtained. Three main categories of partners have been identified in the literature according to horizontal relationships, with competitors; vertical collaboration, among users and suppliers; and institutional collaboration, in which the

relationships with public scientific partners such as universities and research centers are most relevant (Belderbos *et al.*, 2004).

Our proposal is based on the explicit inclusion and direct estimation of the effects that such collaborative relationships for innovation may generate on a firm's efficiency, by way of the 'stochastic frontiers' methodology. In such an analytical framework, two main issues are directly integrated: First, consideration of three types of collaboration agreements, as these can yield different results in terms of firm efficiency. Secondly, the comparison of the effects generated by collaboration on innovation making explicit the potential difference between foreign and domestic firms. The latter may be more integrated into the environment, translating to a higher level of embeddedness that may signify greater collaboration with other agents locally; while foreign firms may show lower involvement levels. The hypothesis developed here directly addresses these questions and seeks to fill the gap in the literature regarding the relationship of these two issues with the impact on the economic efficiency of firms. The empirical test has been conducted thanks to the availability of panel data for manufacturing firms in Spain, allowing us to capture and observe dynamic effects.

The remainder of this paper is organized as follows. We present the literature background and development of the hypothesis in the next section. Section three describes the empirical model and data source, while section four includes the estimation results and discussion thereof. Finally, section five contains some concluding remarks and potential implications for actions of managers and practitioners.

2. Literature background and development of the hypothesis

Knowledge has become a key driver of competition in increasingly dynamic and internationalized markets, while the internal generation of knowledge is sometimes insufficient. This justifies firms in the search for external sources of knowledge beyond their borders, to face competition in increasingly sophisticated market segments. One prominent target is the fact that firms must learn how to manage, absorb, and combine various external knowledge-sources as a response to challenges derived from rapid technological change and the need for innovation imposed by mounting competition (Miotti and Sachwald, 2003, Lo Nigro *et al*., 2014 and Mazzola *et al.,* 2016). The traditional innovation strategy based on internal and specialized R&D has been losing momentum, while the knowledge economy is based on the increasing qualification and mobility of human resources, the higher capacities of suppliers, the expansion of risk capital, and the reduction in product life-cycles (Pisano, 1990). These changes imply that firms need to widen their channels of access to new knowledge, and external sources are more often seen as an opportunity for adding value rather a potential risk. Collaboration, then, is seen as an intermediate step between markets and firms, due to the growing speed of the innovative process and the growing complexity of technologies (Teece, 1986). However, the success of activities carried out to integrate knowledge, when firms take advantage of external sources, depends on the presence of technological opportunities as well as the level of a firm's absorptive capacities. These aspects contribute to defining the ability of firms to exploit external knowledge in favor of their own innovation performance, and they determine how this leads to a higher propensity for collaborating with other agents (Cohen and Levinthal, 1990; Abramovsky *et al.,* 2005).

Three main theoretical bodies help to explain this issue. First, the access to external knowledge can be understood as an incentive to reducing transaction costs, to sharing risks and fixed costs, and to the reduction of those high 'sunk' costs that purely internal R&D implies. This also allows firms to increase flexibility, to reduce the uncertainty inherent to innovative activity, and to obtain economies of scale and the likelihood of innovation success (Williamson, 1975; 1996; Hagedoorn *et al.,* 2000). On the other hand, according to a strategic management view, a framework of collaboration with external agents can be an important driver for the improvement of a firm's competitive position. This may be seen as redundant with the improvement of efficiency, the access to complementary resources, and the exploitation of synergies, since collaboration permits the creation of new competences within an organization (Teece, 1986; Thorelli, 1986; Hamel, 1991; Teece *et al.*, 1997). Finally, industrial organization arguments are based on the problems of market failure related to knowledge generation and appropriation. Collaboration is a path to new forms of knowledge generation, and not only for new products. This is because the higher the levels of incoming spillover and appropriation capacity, the greater the internalization of external knowledge, and the greater the likelihood of R&D collaboration and subsequent successful results (Cassiman and Veugelers, 2002).

Changes to the more traditional model of innovation, motivated by increasing interactions and chain-links, are addressed by Chesbrough (2003a, 2003b) in the 'open innovation' proposal, in which the study of technological collaboration takes center stage. Open innovation means the capacity of firms to take external ideas and knowledge and to combine them with internal R&D. Such diverse forms of collaboration contribute to making innovative activities more dynamic and flexible, without incurring internalization costs, and the motives for firms to establish collaborations are varied. This leads to a significant relationship between a collaborating firm's decisions and the likelihood of repeated recourse to external flows as relevant inputs for the innovation process, implying that those with higher appropriation capacities will be also more keen to collaborate (Cassiman and Veugelers, 2002; López, 2004). Nonetheless, collaboration activities can also adopt the form of research partnerships, developed from relationships based on innovation and implying a significant R&D effort *(*Hagedoorn *et al*., 2000).

Regarding possible external linkages for firms, three main types of partners are identified in the literature, although the motives and forms of collaboration differ among them. First, 'horizontal collaboration' takes place between competitors, the main objectives being the pursuit of economies of scale and scope, as well as reduction of the individual costs associated to innovation, following either risk-reduction or product-diversification strategies. This is more important in high-tech industries because it allows a more rapid recuperation of the resources invested. Second, 'vertical collaboration' implies the participation of customers in the innovation process, and this is considered a strategic asset for reducing the risks associated with the introduction of novelties into the market, and for the expansion of sales through new, innovative products (Von Hippel, 1988). On the other hand, collaboration with suppliers is also convenient, guaranteeing a permanent improvement in quality guided by the objectives of improved efficiency and reduced

costs (Belderbos *et al*., 2004). Finally, 'institutional collaboration' is the third type of collaboration. This has been gaining importance in recent decades, as the involvement of governments in R&D funding initiatives has positively impacted on firms' decisions (Abramovsky *et al.,* 2005). Universities and research centers are not only services providers, but can even become partners in collaborative projects with firms that have left the traditional role of customer to be involved in alliances (Hagedoorn, 2002).

Two additional and relevant aspects to mention are included in the theory of mutlinational enterprises (MNE), as a result of the combination of international economics with views of industrial organization. The first is the relevance of heterogeneity, since those firms with higher productivity levels are usually more internationalized (Helpman *et al*., 2004; Nockle and Yeaple, 2007; Markusen and Stähler, 2009). The diversity of firms' strategies has indeed reduced the relevance of the difference between vertical and horizontal FDI, mainly due to the international fragmentation of the value chain. This combines with MNE localization patterns, mainly in terms of those knolwedge-intensive industries in which standarized phases of the productive process are located abroad, along with strategic activities such as R&D (Gorg, 2000; Mudambi, 2008). The second involves the higher relevance assigned to advantages defined at the level of individual firms or subsidary units (Barlett and Ghoshal, 1998; Forsgren *et al.*, 2005). The individual action of units within an MNE are combined in a more complex network view (Barlett and Ghoshal, 1986); rather than replicas of the headquarters, subsidiaries contribute to competitive advantages on an international basis. In this vein, innovation becomes a key aspect to distinguishing among the differentiated mandates received by subsidiaries within the MNE, this being more likely in more creative subsidiaries (Jarillo and Martínez, 1990; Roth and Morrison, 1992; Birkinshaw, 1996). Some such subsidiary units are able to gain a higher level of autonomy, bring them closer to global mandates as 'centers of excellence', while others strategies are focused on the adaptation to the local foreign market (Birkinshaw and Morrison, 1995; Nobel and Birkinshaw, 1998). Overall, the development of different typologies has contributed to increased attention on the knowledge-seeking functions of subsidiaries and on the factors explaining how R&D and innovation-related activities are assigned within the MNE (Gupta and Govindarajan, 1991; Feinberg and Gupta, 2004; Phene and Almeida, 2008; Ambos, 2005).

Looking at the relationship between host territories and the knowledge-creation function of subsidiaries, some contributions reveal that the development of new products and the strategic orientation of firms are factors for identifying how creative mandates are assigned (Cantwell, 1995; Cantwell and Mudambi, 2005; Cantwell and Piscitello, 2002, 2007). This renewed vision of the MNE underlines the importance of technological knowledge-searching strategies abroad. It is plausible, then, to accept that subsidiaries do have this function, and that they contribute to the establishment of collaboration networks that facilitate knowledge flows, eventually favoring the overall corporation, as has been shown in the related literature (Barkema and Vermeulen, 1998; Frost, 2001; Piscitello, 2004; McCann and Mudambi, 2005; Singh, 2007; Mudambi, 2008).

In this context, the concept of embeddedness has been gaining in importance. The global strategies of large internationalized firms, together with the relationship between science and technology, reveal geographical proximity as another important element. Also, local capacities become crucial as an attractiveness factor for new investments. The notable process of internationalization affecting key activities such as R&D and innovation confers greater independence and autonomy to subsidiaries in foreign contexts. Moreover, this process also has effects on the productive and innovation systems of host economies (Pearce, 1999; Archibugi and Ianmanrino, 2000). Public R&D labs, the local infrastructure, the education system, and the scientific base are, in fact, valuable elements for the R&D internationalization of foreign firms. These elements, connected to the network dynamics, are clearly conditioned by the R&D levels of foreign firms as well as how these evolve toward becoming competence-creating units:

According to this background, and assuming that collaboration for innovation is clearly defined by firms' strategies, our proposal is that the impact on the performance of firms, in terms of permitting them to improve efficiency, depends upon two main drivers: the type of collaboration, and the level of embeddedness of firms in their environment or local context. Thus, we propose to test the following set of hypothesis:

- First, because competition has become an imperative force that has placed innovation at the core of firms' competitive strategies, it is expected that the effects of Horizontal Collaboration in the efficiency of firms is positive (H1); but this may differ between foreign and subsidiary firms due to their relative strentgh and market-power, vis-à-vis their competitors (H1a). Moreover, the persistence of likelihood to collaborate for innovation would denote a modulating effect: the higher the intensity of collaboration, the larger the effect on firm efficiency (H1b).

- Secondly, the traditional role assigned to suppliers and customers as sources of innovation leads us to expect that Vertical Collaboration has a positive impact on a firm's efficiency (H2). Although differences between domestic and foreign firms are not here expected, it should be noted that differences on the innovative strategies of foreign firms are linked to the mandates of subsidiaries. The fact that headquarters assumes the innovation and product-differentiation risks, or that this takes place at the level of the individual unit, implying that foreign firms have a creative mandate (are competence-creating units) If this is the case, differences with domestic firms are to be expected (H2a). Moreover, where a higher level of embeddedness in the firm's environment prevails, a higher persistence of collaboration would predominate (H2b).

- Third, it can be expected that the impact of Institutional Collaboration is positively related to the efficiency of firms (H3). However, the effects of institutional collaboration for innnovation on firm effiency are moderated by the firm's level of embeddedeness in its environment or system of innovation. Therefore, it is expected that institutional collaboration differs between domestic and foreign firms (H3a). In addition, the persistence of this type of collaboration with other institutions may effect different results over time; in particular, if collaboration on innovation is persistent, positive results on efficiency are more likely (H3b).

3. Empirical model and data description

In the different approaches for measuring the productive efficiency of firms, specific methods can identify the frontiers of the most efficient practices. In particular, two main methodologies can be distinguished, depending on whether the type of efficiency frontier is deterministic or stochastic. The main drawback of deterministic frontiers is that every deviation is interpreted as a measurement of inefficiency. For this reason, no consideration is given to the possibility that productive activity may be affected, for instance, by exogenous stochastic shocks, or by errors in measurement. On the other side, stochastic frontier models consider that each firm has its own stochastic frontier, from which it may deviate systematically. The latter is the methodological approach followed in this paper.

For the stochastic frontier, the error parameter is composed by two elements. Firstly, a symmetric term v_i that contains the effects of random variables, exogenous shocks and measuring errors, among others. Secondly, an asymmetric component u_i that measures systematic deviations from the frontier, and that may be interpreted as an efficiency indicator. In this way, the stochastic production frontier may be specified as equation (1):

$$y_i = f(x_i;\beta)\exp(v_i - u_i) \qquad (1)$$

where: y_i represents the *output* of the productive unit *i*, x_i is an *input* vector, and β is a vector of parameters to be estimated. The elements of u_i are assumed to be independent and distributed identically, while a normal distribution is assumed for the symmetric component of the error v_i $(v_i \rightarrow N(0,\sigma_v^2))$

Once the firm efficiency indicators are obtained, it is customary to implement a regression analysis in order to find variables explaining differences in efficiency between productive units. However, a disadvantage of this approach is that if a variable has explanatory power on the efficiency indicator in the second stage, it needs to have been included in initial specification (first stage). To the contrary, if such a variable has already been included as a regressor in the first stage, it should have no explanatory power in a second stage regression.

As an alternative, Battese and Coelli (1995) developed a panel model in which parameters of a stochastic production frontier and variables affecting the efficiency of productive units are jointly estimated[1]. This methodological approach is also designed to introduce the possibility that technical inefficiency may change over time, and to include other variables in order to explain the time-path of firm efficiency. The generalization of expression (1) to the stochastic production frontier in a data panel context is straightforward. In this context, the indicator of technical inefficiency in production (u_{it}) is assumed to be distributed independently and extracted from a normal distribution truncated at zero, with mean δz_{it} and variance σ_u^2 and specified as equation (2):

$$u_{it} = \delta z_{it} + w_{it} \qquad (2)$$

where: z_{it} is a vector of variables explaining technical inefficiency, which may change over time, δ is a vector of parameters to be estimated, and w_{it} follows a normal distribution truncated at point $-\delta z_{it}$ with zero mean and variance σ_w^2. This implies that $w_{it} \geq -\delta z_{it}$ and is consistent with assumptions on the distribution of inefficiency terms u_{it}.

1 Previously, Kumbhakar *et al.* (1991) and Reifschneider and Stevenson (1991) proposed stochastic frontier models in which inefficiency was specified as a function of a set of variables. The proposal by Battese and Coelli (1995) allows extension of the model to a panel data structure.

Data used in this paper are based on the *Survey on Business Strategies* (*Encuesta de Estrategias Empresariales*). This source provides, at firm level, data for 20 manufacturing industries in Spain. It is carried out yearly by the Fundación SEPI with the support of the Spanish Ministry of Industry. The reference population is integrated as those firms with 10 employees or more. Firms with between 10 and 200 employees are chosen by a random sampling scheme, and the rate of participation is around 4%. For firms employing more than 200 employees, the rate of participation is about 60%. The main advantages of using this statistical source are its representativeness and the availability of an extensive range of information on firm strategies. Contrarily, the main disadvantage of the dataset is that the analysis is confined to manufacturing firms.

The stochastic frontier model is estimated by maximum likelihood using a Cobb-Douglas production function (3):

$$\ln y_{it} = \beta_0 + \beta_1 \ln L_{it} + \beta_2 \ln K_{it} + \\ + \beta_3 \ln IC_{it} + \beta_k industry_{it} + (v_{it} - u_{it}) \qquad (3)$$

where: *y* is the output, measured as the firm's income deflated by industrial price indices. *L* is labour input (number of workers) and *IC* is intermediate consumptions, also deflated by industrial price indices. The capital input (*K*) used in this work is a variable from the Survey on Business Strategies estimated by permanent inventory method. Finally, *sector* is a set of industry dummies. We use a 2-digit classification of 20 industrial activities[2].

In addition, the technical inefficiency function is specified as equation (4)

$$u_{it} = \gamma_0 + \gamma_1 size_{it} + \gamma_2 age_{it} + \\ + \gamma_3 foreign + \gamma_4 collaboration \qquad (4)$$

Where both, *size* and *age,* are two classical control variables for productivity estimations. In this paper, firm *size* is measured with a binary variable that takes value 1 for companies with over 250 employees, and 0 otherwise. The second control variable, *age,* is measured by the number of years since the firm was created. Finally, two more dummies appear in equation (4): *foreign*, which takes 1 when more than 50% of a firm's capital belongs to foreign owners, and 0 otherwise. *Collaboration* takes 1 if the firm is involved in any kind of agreements for collaboration on innovation, or 0 if otherwise. Definitions can be found in Table A1 in the Appendix.

Regarding collaboration variables, as stated earlier, we have classified these activities into three groups: vertical, horizontal, and institutional. The case of *horizontal* collaboration refers to agreements with other (competitor) firms, while *vertical* collaboration attempts to capture relations of collaboration on innovation among firms taking the role of clients or suppliers. Finally, collaboration on innovation activities with public centers of research or with universities is captured by the *institutional* variable. All three variables take 1 when firms are involved in these types of collaboration and 0 otherwise.

With regard to our sample of manufacturing firms, 32.3% had some kind of collaboration

2 As usual, we leave out one sectorial dummy variable. In this case, the omitted sector is "other manufacturing activities".

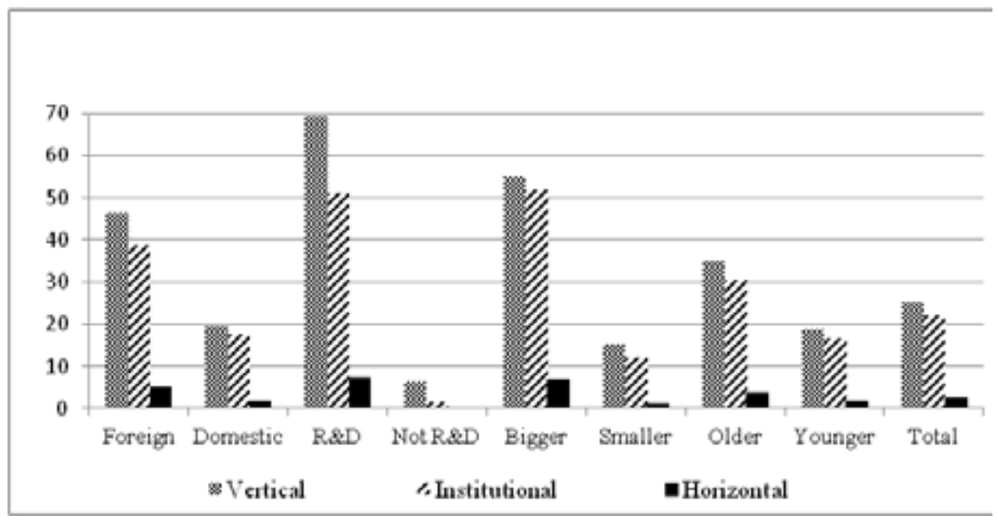
agreement with other firms and/or institutions, at least once in the period 1998-2007[3]. As shown in Figure 1, *vertical* is the most common type of collaboration among firms (25%). Collaboration with universities and technological centers shows a similar relevance (22%), while only 2.7% of firms engaged in horizontal collaboration with competitors.

We combine information about the collaboration activities of firms with characteristics such as *age* and *size*, the two control variables used in equation (4). Accordingly, these seem to have influence on collaboration for innovation, especially the latter: more than 50% of large firms (over 250 workers) have had vertical and/or institutional collaborations agreements. This figure amounts to 7% for horizontal agreements. Another relevant characteristic of firms is ownership. In particular, the percentage of foreign firms (as defined above) involved in collaboration agreements on innovation is about twice the percentage corresponding to domestic firms. Finally, there is a radical influence from internal R&D expenditures on firm collaboration, as shown in Figure 1, revealing that external sources of knowledge are complementary to the internal ones.

4. Discussion of results

We discuss in this section the results obtained from simultaneous maximum likelihood estimations of equations (3) and (4) for the sample of manufacturing firms described above. We also present the results of the analysis of those key variables related to collaboration, conducted separately for the two groups of firms (domestic and foreign), classified according to the participation of foreign capital[4]. The number of firms considered for these estimations is 2,168, although availability of information was not constant throughout the period 1998–2007. Thus a smaller number of firms was considered for certain years. Finally, we proceed with the estimation of an unbalanced panel.

FIGURE 1. COLLABORATION TYPES



3 Belderbos *et al*. (2004) found a similar weight for Dutch firms (30 %) for the period 1996-1998.

4 For splitting the sample between groups of domestic and foreign firms, the criterion used for inclusion in the latter is that a percentage of at least 50% of a firm's capital belong to foreign owners.

Results for the production function with the complete sample are as expected. As shown in Table 1, the associated elasticity is 0.27 for labour, 0.07 for capital, and 0.66 for intermediate consumption. These results point out constant returns to scale, as is common when aggregated production functions are estimated. In fact, the results are congruent with those obtained by Martín and Suárez (2000) and by Quirós and Rodríguez (2010) with the same source of statistical information, although the analyses in those contributions corresponded to an earlier period than was considered in this work. Another important parameter in our estima-

TABLE 1. PANEL FRONTIER PRODUCTION FUNCTION. (Total Sample)

Production frontier	
Constant	3.779(***) (127.299)
Materials	0.657(***) (255.756)
Labour	0.267(***) (69.229)
Capital	0.069(***) (29.672)
Industry Dummies (*)	
Inefficiency function	
Collaboration agreements (any type)	-0.032(***) (-2.721)
Age	0.015 (1.231)
Size	-0.078(***) (-23.924)
Foreign Firms	-0.426(***) (-19.286)
Sigma squared	0.087 (***) (91.771
Gamma	0.012 (***) (3.460)

	Industry Dummies (*)	BETA	T-RATIO
1	Meat products	0.036	1.922
2	Food and tobacco products	-0.092	-6.040
3	Beverages	0.076	3.643
4	Textiles	-0.006	-0.395
5	Leather. shoes	-0.079	-4.311
6	Wood products	-0.022	-1.203
7	Paper products	-0.006	-0.344
8	Graphic Arts	0.058	3.547
9	Chemical and pharmaceutical products	0.182	11.271
10	Rubber and plastics	0.050	3.085
11	Non-metallic minerals	0.074	4.711
12	Ferrous and non-ferrous metals	0.151	8.237
13	Metallic products	0.086	5.773
14	Farming and industrial machinery	0.082	5.080
15	Informatics. Electronic and optical products	0.193	10.183
16	Electric machinery and materials	0.082	4.930
17	Motor vehicles	0.057	3.400
18	Other transport materials	0.071	3.736
19	Furniture	-0.130	-7.808
20	Other manufacturing industries (omitted industry)		

tion is γ. This reflects the part of the error variance that can be explained by the inefficiency equation. If the null hypothesis (γ=0) were accepted, then the inefficiency equation would have had to be removed from the model. But as can be seen, this parameter shows the need of including the inefficiency equation.

Table 1 also shows the effect of explanatory variables on the inefficiency equation (4). As we expected, firm size is negatively associated with inefficiency. In this case, larger firms may take advantage of potential economies of scale, although coordination diseconomies could lead to inefficiency if firms are too large. However, it is unlikely that such diseconomies were significant in this case, due to the reduced average size of Spanish manufacturing firms[5]. The results obtained related to firms' *age* are not significant. In this case, the theoretical advantage from knowledge accumulation and learning processes (Jensen *et al.*, 2001) were not especially relevant for the sample used here.

On the other hand, the presence of foreign ownership in the equity capital of manufacturing firms is negatively associated with the distance from the efficiency frontier. In other words, foreign[6] firms seem to be more efficient than domestic firms in Spain. This is particularly interesting when taking into account the abundance of literature in recent years that has emphasized the relevance of internationalization to explain heterogeneity of efficiency across firms (Helpman *et al.*, 2004; Melitz, 2003, Yeaple, 2009). This serves to reinforce the results obtained in other works such as Bottasso and Sembenelli (2004) or Bin *et al.*, 2007. Moreover, productivity differentials of foreign-owned firms in comparison to domestic is a general assumption of the economic literature regarding spillover effects (Kokko, 1994; Blomstrom and Kokko, 1998), an aspect that serves as justification for several empirical works on the presence of multinational companies in Spain (Álvarez and Molero, 2005; Quintás *et al.*, 2008; Santamaria *et al.*, 2009; Rosell-Martínez and Sánchez, 2012).

The effects of collaboration on innovation on the productivity of firms for the whole sample are shown in Table 1. Collaboration has a significant effect as a source of efficiency for manufacturing firms, whatever the type of collaboration undertaken. This is an expected result in works that analyze collaboration among firms and other institutions (Pippel, 2013).

Reaching more deeply into the efficiency effects generated by collaboration on innovation, the sample has been divided into two groups: domestic firms and foreign firms, according to the capital participation of foreign owners, as defined. The premise is that the level of embeddedness of firms in their environment may impact differently on the collaboration effects on efficiency; for this reason, it is plausible to suppose that domestic firms are more embedded in their environment than are foreign firms. In Table 2, five specifications of the general estimation are observed. In column A, the collaboration variables are presented in current values. Columns B, C, and D show these variables with 1 lag, 2 lags, or 3 lags, respectively[7]. Finally, column E introduces the collaboration variables in cumulative terms; instead of dummies variables taking 1 or 0, these *intensity* variables take the number of collaboration agreements that occurred during the period 1998-2007.

5 Pagano and Schivardi (2003) point out that the average firm size in Spain was around 60% that of other European Union countries.

6 As indicated before, we have defined a firm as foreign-owned when more 50% of its capital belongs to foreign owners.

7 Most works analyzing collaboration agreement effects use lags of this type in estimations (Pippel, 2013).

TABLE 2. PANEL FRONTIER PRODUCTION FUNCTION.

Inefficiency function

Foreign Firms

	A (not lag)	B (1 lag)	C (2 lags)	D (3 lags)	E Intensity
Collaboration					
Horizontal	-0.256(***) (-23.528)	-0.546(**) (-1.750)	-0.521(***) (-9.916)	-0.949(*) (-1.606)	-0.021(***) (-3.892)
Vertical	0.017(*) (1.450)	-0.088 (-0.967)	-0.013 (-0.575)	-0.056(*) (-1.540)	-0.004(***) (-2.825)
Institutional	0.040(***) (2.877)	0.568(**) (2.192)	0.476(**) (1.793)	0.099(***) (2.846)	0.012(***) (4.924)

Domestic Firms

	A (not lag)	B (1 lag)	C (2 lags)	D (3 lags)	E Intensity
Collaboration					
Horizontal	-0.199(*) (-1.508)	-0.179(**) (-2.283)	-0.107(***) (-2.719)	-0.138(***) (-2.521)	-0.033(***) (-4.441)
Vertical	-0.01 (-0.065)	-0.007 (-0.473)	-0.0003 (-0.0208)	0.009 (0.860)	-0.005(*) (-1.607)
Institutional	-0.039 (-1.099)	-0.036 (-1.136)	-0.091(***) (-4.406)	-0.079(***) (-2.676)	-0.005(**) (-2.119)

Significant differences exist between the two groups of firms when current data are used, in column A. For the subsample of **foreign firms,** the three kinds of collaborations are statistically significant, although the signs of the parameters differ. Only horizontal collaboration seems to reduce the inefficiency of firms, meaning that collaboration with competitors for innovation plays a relevant role in terms of firm performance. By contrast, institutional and vertical agreements show a positive sign, meaning that these types of collaboration have a positive impact on the inefficiency equation. This is an unexpected result, and it can be explained in a first round, assuming the necessary time-lapse before the appropriation of results from collaboration on innovation emerges and generates an impact on firms' efficiency.

In fact, the parameter corresponding to the vertical collaboration variable in the

estimation and taking 1 lag (column B) adopts an opposite sign, but this is not statistically significant; thus do we look to specification of the estimation in the third lag (column D) to comment on results. In this column, vertical collaboration becomes significant, and the negative sign on inefficiency denotes a positive impact on firm efficiency. However, this is not the case for the institutional variable; the corresponding parameter maintains a positive sign in the inefficiency equation. A potential explanation in this case could be the existence of an auto-selection bias, not controlled in the model. Firms that have decided to participate in collaboration agreements with universities or public centers may show initially low levels of efficiency. These levels would likely tend to grow as a result of such a collaboration process, but the bias of initial low efficiency may prevail in the productivity improvement sequence. The results obtained here for foreign firms support this last hypothesis. At the same time, the reasons these firms might continue this sort of collaboration when effects on efficiency are not positive can likely be found in the very motives for collaboration. In the case of a foreign firm seeking collaboration in a host country, institutional collaboration can be seen as a way of extending contacts and network' linkages locally.

Interestingly, the results obtained for the subsample of **domestic firms** are very different from those corresponding to foreign firms. First, only the estimated parameter of horizontal collaboration in column A shows a statistically significant effect, with a sign similar to that in the foreign firm group. The negative sign of the parameter reveals a positive impact on firms' efficiency. This result persists across the three estimations in which different lags are taken. Secondly, vertical collaboration is not significant in any specification, meaning it is not possible to affirm that collaboration with customers and suppliers as adopted by domestic manufacturing firms in Spain have positively impacted those firms' efficiency. The parameter associated with the institutional variable is not statistically significant in the estimations results shown in column A and B; however, this variable becomes significant in the estimations with 2 and 3 lags –columns C and D. This result is opposite that obtained for foreign firms, and it means that for domestic firms, increases in efficiency linked to collaboration on innovation with technological institutions and universities overcome those firms' selection bias.

Finally, column E shows the three types of collaboration, with a different specification, introducing the number of collaboration agreements by firms in a cumulative way. This allows us to consider the importance that intensity of collaboration for innovation has on the performance of firms. This *intensity* variable also permits us to check whether efficiency gains can be associated to persistence, defining a long process where repetition plays an important role in the success of collaboration on innovation. One aspect to mention, after observing the results, is that all estimations using the intensity variables are statistical significant[8]. Another is the negative sign of the parameters of all these variables, with the sole exception of institutional collaboration for the group of foreign firms. In this subsample, the institutional variable still generates the unexpected effect on efficiency previously mentioned in relation to current and lagged variables. Apart from the unanticipated result of institutional collaboration on foreign firms, the negative sign for the remaining parameters

8 This result is obtained with different levels of statistical probability: the parameter associated to the vertical variable for domestic firms shows a lower level of significance.

–vertical and horizontal– confirms that agreements for collaboration on innovation can be accepted as a source of improvement for firm efficiency even among foreign firms, as expected. Meanwhile, in domestic firms, the effect of collaboration on innovation is more pervasive, since the negative sign and significant parameters apply to all three categories. This makes possible a confirmation of the hypothesis of embeddedness, since the impact on efficiency results is more clearly identifiable when dynamics are explicitly considered, and when linkages with other firms and agents are persistent, and a longer-term view is adopted.

Accordingly, the hypotheses having been tested, it is possible to accept/reject them as follows:

Our findings allow us to confirm H1, it being possible to affirm that horizontal collaboration generates a positive impact on the efficiency of firms. Differences between domestic and foreign firms have not been found, so it is not possible to accept H1a. Moreover, since the effect of intensity of collaboration is statistically significant for both domestic and foreign firms, H1b is confirmed, and the argument regarding the relevance of a firm's experience on collaboration with competitors in order to derive positive impacts on efficiency is validated.

Secondly, it is not possible to say that vertical collaboration on innovation always generates a positive result on firms' efficiency, hypothesis H2 not being confirmed. However, positive effects are detected in foreign firms when a 3-lag period is considered, implying that collaboration with customers and suppliers does not have an immediate impact, but rather depends on a longer tradition of agreements with said agents. The difference with respect to domestic firms brings us to accept H2a. It is also particularly notable that the intensity of collaboration on innovation is relevant to generate positive effects on the efficiency of both foreign and domestic firms, H2b being confirmed.

Finally, the hypothesis regarding institutional collaboration could not be accepted (H3), while the differing results obtained for foreign and domestic firms allow us to accept H3a. Nonetheless, particular comments must be made, since there are no positive effects of this type of collaboration on the foreign firms' efficiency levels, while in the case of domestic firms, there are some positive impacts on efficiency, when 2 and 3 lags of the variable are considered. The intensity of collaborative agreements with other institutions is associated to efficiency gains only for domestic firms that, in general, have closer linkages with other agents in the local environment. This implies the acceptance of H3b only partially; however, it is possible to confirm the argument that the more embedded the firms are, the higher the effect of institutional collaboration on firms' efficiency.

5. Conclusions

Firms very often manifest the need to access external sources of knowledge for purposes of innovation through the establishment of collaborative relationships, whether with other firms or with agents present in the local system of innovation. This can be complementary to a firm's own internal R&D, or it can adopt a more substitutive role. The latter case is more likely in firms farther from the frontier, such as those found in more

traditional or low-technology activities. The high level of 'sunk' costs together with the risk associated to R&D, and the potential low appropriation of knowledge, are a few of the main reasons explaining the lack of exclusive R&D or other innovation activities undertaken by firms without collaborative partners. This paper tries to provide new insights into the relevance that collaboration for innovation may generate on the efficiency of firms.

This contribution shows the relevance of the decision by firms around selection of collaborative partners, and the relevance of differentiating between horizontal, vertical, and institutional collaborative relationships. The prevalence of a positive effect derived from collaboration with competitors allows us to affirm that risk-sharing is a powerful reason for taking that decision, bearing in mind the increasing complexity of many technological fields that require the combination of the scientific and technical capacities of individual firms. However, our findings do not confirm that collaboration upstream and downstream always has a positive impact on firm efficiency. Dynamics do seem to be a determinant factor for the generation of positive effects derived from vertical relationships. These are more time-dependent – an aspect that acquires greater relevance for foreign firms in Spanish manufacturing industries. Moreover, the effects of institutional collaboration on firms' performance are even less clear than as regards horizontal or vertical collaboration.

On the other hand, sporadic collaboration agreements are less efficient, while persistence of collaboration seems to be a crucial aspect that leads to better results in terms of firm performance. This result is more relevant than whether a firm is foreign or domestic. Meanwhile, our empirical findings reinforce the role of embeddedness as a pillar for understanding the topic. In sum, the inclusion of embeddedness of firms in their environment in the analysis gives more support to our findings, confirming that the impact on efficiency for both foreign and domestic firms behave differently according to how creative and integrated foreign subsidiaries are in a particular location.

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APPENDIX

TABLE A1. DEFINITION OF VARIABLES.

Variable	Definition
Collaboration agreements (any type)	Dummy variable adopting value 1 if Firm engages in collaboration on innovation; and 0 elsewhere
Age	Number of years from the moment of Firm start-up
Size	Dummy variable adopting value 1 if the number of employees is larger than 250; and 0 elsewhere.
Foreign Firms	Dummy variables taking 1 when more than 50% of a firm's capital belongs to foreign owners; and 0 elsewhere.
Vertical collaboration	Dummy variable adopting value 1 if Firm engages in collaboration with suppliers and customers; and 0 elsewhere.
Horizontal collaboration	Dummy variable adopting value 1 if Firm engages in collaboration with competitors; and 0 elsewhere.
Institutional collaboration	Dummy variable adopting value 1 if Firm engages in collaboration with universities or technology or research centers; and 0 elsewhere.
Intensity of collaboration	Sum of total of collaboration agreements taking place in the period 1998-2007

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