STI-DUI learning modes, firm-university collaboration and innovation output

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Abstract

In this study, the relationship between the use of collaborative agreements and the firm's innovation output is examined. Firms may innovate using partnerships linked to a "science and technology-based" (STI) mode of learning, as well as partnerships linked to a "learning-by-doing, by-using and by-interacting-based' (DUI) mode of learning. Within this view, universities are important STI partners that provide flows of science and technology driven knowledge leading to innovation. A fixed-effects logit estimation is applied on an extensive panel of Spanish manufacturing and service firms to analyze the separate and combined impact of collaborative agreements associated to STI and/or DUI modes of learning, with a special emphasis on the role of partnerships with universities. Even though STI and DUI partnerships are both important for product and process innovations, the results demonstrate that different types of collaboration are related to different types of innovation. While product innovation benefits more from the combination of DUI and STI partnerships, process innovation is more closely related to DUI partnerships. Apart from that, collaborations with universities, in combination with DUI partners, leads to a higher likelihood of product innovation. In contrast, process innovations are less dependent on collaborations with universities than on collaborations with other STI partners.

Keywords: innovation, technology, interaction, learning, STI-DUI, university collaboration, Spain

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1 Introduction

The literature on evolutionary economic theory holds that technological change and innovation are key drivers of economic growth, as they contribute to moving territories forward through sequential economic stages (i.e. resource-driven, efficiency-driven and knowledge-driven) (González-Pernía, Peña-Legazkue and Vendrell-Herrero, 2012). Yet, our understanding to explain the processes through which firms innovate remains far from being complete. While some authors suggest that firms innovate through the use and exchange of codified knowledge, which is mainly based on the investment in science and technology (e.g., research and development - R&D, patenting, information and communication technology, etc.), others argue that innovation comes from the use and exchange of tacit knowledge, which is mainly based on the experience and informal interactions among agents (Griliches, 1979; Lundvall, 1992). Jensen et al. (2007) identify these two modes of learning as Science, Technology and Innovation (STI) and Doing, Using and Interacting (DUI), and suggest that firms combining both approaches are more likely to introduce new products than those specialized only in one of them. However, Jensen et al.'s conclusions are based on a static analysis that does not disentangle how specific STI and DUI components may have a differentiated impact on different types of innovation (i.e., not only product but also process innovation).

In globalized learning economy, firms hardly innovate alone. On most cases they must collaborate with other partners to successfully introduce innovations into the market (Meoli et al., 2013). The collaboration with universities is an important component of the STI mode of learning. Of course, the role of the university may differ across industries (Isaksen and Karlsen, 2010), but collaborations for innovation between firms and universities are dominated by the STI mode of learning as this type of partner constitutes a source of research results and scientific knowledge.

Recent works have tried to contribute to this debate through the analysis of firm collaborations dominated by (or linked to) the STI and DUI mode of learning (Fitjar and Rodríguez-Pose, 2013). Yet, the perspective adopted is static and the specific role of universities and its interaction with other type of partners are not analyzed.. Thus, the literature is not conclusive enough as to confirm the effectiveness of distinct and combined learning modes, and the role of universities for achieving enhanced innovation outcomes. Further research is needed to better understand how *inter-firm* learning modes in general, and firm-university partnerships in particular, influence the effort made by organizations on spurring innovation.

The purpose of our paper is to shed some light on this research strand. More precisely, we add an analysis of the separate and combined effect of science-based (STI) and practice/interaction-based (DUI) modes of learning on innovation output measured both in terms of product and process innovations. . As Fitjar and Rodriguez-Pose (2013), we distinguish two sorts of cooperative partnerships: STI and DUI partnerships. STI partnerships include research agreements of firms with universities, technology centers, consulting services and research labs; whereas DUI relationships embrace collaborative agreements of firms with customers, suppliers and industry competitors.[1] However, within the STI partnerships category we differentiate between firm relationships with "universities" and firm collaborative agreements "with other STI partners". The rationale behind this distinction is that *basic research* seems to be a more common exploratory task undertaken by "firm-university" partnerships, whereas *applied research* is typically a more market-oriented assignment conducted between firms and other STI partners (i.e., technology centers, consulting services, and research development labs).

This double effort, which is analyzed in dynamic terms through extensive panel data, is original and adds new insights, reflections and evidence that show: 1) the usefulness of combining the two learning modes for product innovation; 2) the importance of DUI drivers alone for process innovation; 3) the relevance of involving the STI collaboration with universities for product innovation; 4) the importance of collaboration with others STI agents for process innovation.

Overall, we expect to contribute to the extant literature at least in three ways. Firstly, innovation cannot be studied as a sole inventive activity (Meoli et al., 2013); it is a multifaceted task that shows multiple manifestations. Following this view, we show how distinct STI and DUI practices affect differently product and process innovation. Secondly, we explain the role of universities as a critical STI partner for pursuing both product and process innovation. Nonetheless, partnerships with universities seem to be necessary, but not sufficient for conducting (and implementing) innovation by firms. Thirdly, prior studies have empirically examined this subject under a static view. The literature lacks research which explores this phenomenon from a "dynamic". Our study addresses this caveat by conducting panel regression analysis. Indeed, our work goes beyond the prominent "one-region, one-period" type of analysis of the literature, as we examine firms from all Spanish regions over multiple-periods accounting for temporal heterogeneity.

The paper is structured as follows. In section 2, we explain the foundations of our broad model by which the linkage between STI and DUI learning modes, firm-university collaboration and innovation output is explained. In section 3, we describe the data and methods used for our empirical work. Results are discussed in section 4, and the study ends with main conclusions and implications.

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[1] In this sense, we vary our approach vis-à-vis the former seminal work of Jensen et al. (2007) and other previous works (Parrilli and Elola, 2012; González-Pernía, Parrilli and Peña-Legazkue, 2012) as we do not count in this case with indicators of the internal business organization.

2 Learning modes, research partnerships and innovation

2.1 STI and DUI learning modes

The importance of specialized innovation agents (STI type), such as universities, has been recognized at all levels, including the political (Mowery and Sampat, 2005), on which basis the European Commission and Parliament approved the Lisbon Agenda 2000 within which the importance of explicit R&D activities are identified as a crucial driver of economic growth. Within this approach, and thanks to the high specialized expertise of its staff and the critical mass of resources devoted to explore new knowledge and test it in labs facilities, the university has been identified as a critical source of knowledge inputs and intermediate innovation outputs (e.g. scientific publications, patents and sometimes academic spinoffs). For this reason, it has been integrated in the innovation system literature in an outstanding position, i.e. the 'triple helix' approach in which it catalyzes the effective interaction for innovation between the government and the business sector or the society as a whole (Etzkowitz and Leydersdorff, 2000; Breznitz and Feldman, 2013). According to several authors (Woerter, 2012; Bozeman et al., 2013; Fukugawa, 2013; Hewitt-Dundas, 2013), the university is expected to act as an agent that both interacts voluntarily and directly with companies at the same time that it also generates knowledge spillovers that are indirectly captured by those and other agents (i.e., small firms) (Audretsch, 2013).

Notwithstanding this general agreement on the importance of STI agents and drivers, some scholars identified advanced countries that produced a very good innovation and economic performance in spite of the relatively lower investments in R&D and infrastructures. It was the case of Denmark and Norway, in the North of Europe (Gertler and Asheim, 2006), which generated well-ranked innovation output rates and economic performance on the basis of a different set of innovation drivers (Asheim and Parrilli, 2012). The increase in productivity of these regions seems to be the result of learning-by-doing practices. This reasoning has been developed by Lundvall and other scholars by extending this approach to include the interactive driver as a key means to co-generate and transfer relevant knowledge within the organization (Kline and Rosenberg, 1986) and among firms and organizations in the innovation system (Lundvall, 1992).

This more complete view of innovation has responded to the so-called 'innovation paradox' that was identified in those countries where most firms did not produce an innovation output (e.g. publications, patents, new products, new designs) corresponding to the volume of classic knowledge and innovation inputs that are introduced in the company (e.g. R&D expenditure, infrastructures, human capital) in comparison to firms operating in other countries in similar competitive conditions. For example, Swedish companies (and the country as a whole) have long been considered stuck in an innovation paradox vis-à-vis firms in countries such as Norway and Denmark that invested comparatively less in such inputs. The novelty of the theoretical debate on the importance of interactive- and practice-based learning helps to explain the high effectiveness of the latter firms and countries that would otherwise be incomprehensible on the basis of STI inputs alone.

In general, the STI learning mode contributes to the generation of advanced scientific and technological knowledge, often associated to analytical processes driven to identify natural principles and mechanisms that can be applied to all firms and in industries with a preference for chemicals, pharmaceuticals, biotechnology and nanomaterials; the DUI approach alone adds the possibility of learning-by-doing, by-using and by-interacting that promote the translation of scientific, analytical knowledge inputs into synthetic knowledge that more easily deliver outputs that are utilized in engineering-based businesses and in industries such as machine-tools and automotive, shipbuilding, as well as many traditional manufacturing sectors (Asheim and Coenen, 2006). Other related types of DUI learning practices may be added such as learning-by-licensing, which may also integrate additional opportunities for business innovation outputs (Wang et al., 2013). The combination of the two (STI+DUI) is expected to combine the strength of the first type of knowledge with the second in a way that generates more scientific knowledge output and, simultaneously, catalyze stronger business interactions that enrich the innovation output with new adaptations and transformations.

Such ideal approach has been analyzed in various geographical contexts, such as China (Chen et al., 2011), Scandinavian countries (mainly Denmark and Norway; see Jensen et al., 2007; Aslesen et al., 2011; Fitjar and Rodríguez-Pose, 2013; Isaksen and Karlsen, 2010), and Spain (Parrilli and Elola, 2012). While some studies support that both STI and DUI contribute positively to innovation output, other studies present more nuanced outcomes (Chen et al., 2011; Parrilli and Elola, 2012; Fitjar and Rodríguez-Pose, 2013).

2.2 Determinants of product and process innovation

We expect that the STI learning mode affects positively innovation as its core activity (R&D) tends to discover and test new product properties, qualities, configurations (Chen et al., 2011; Fitjar and Rodríguez-Pose, 2013). Similarly, the DUI learning mode is expected to influence innovation through exchanges and interactions among workers or among managers and clients, suppliers and service providers in order to creatively improve the way activities are developed (Jensen et al., 2007; Chen et al., 2011). In this sense, hypothesis (1a) is analyzed in terms of collaborative agreements with either STI types of agents (i.e. universities and technology centers) or DUI types of agents (i.e. clients and suppliers) vis-à-vis firms that do not collaborate with any partners.

Our hypothesis (1b) goes in line with some previous analyses on Denmark and Norway (Jensen et al., 2007; Aslesen et al., 2011), where the combined effect of STI and DUI types of collaboration is tested vis-à-vis the single effect of STI collaboration or DUI collaboration. Our conjecture is that the innovation output benefits from the combination in which the firm absorbs both scientific and experience-based knowledge inputs from both STI and DUI sorts of partners.

Hypothesis 1a: Firms that conduct research collaborative agreements (i.e., either with STI partners, DUI partners or both) are more likely to produce product and process innovation than their counterparts.

Hypothesis 1b: Firms collaborating simultaneously with partners linked to STI and to DUI modes of learning are more likely to introduce process and product innovation than those which collaborate with only one type of partners (i.e., either STI or DUI).

We introduce additional hypotheses to capture the effect on innovation of firm-university partnerships, echoing the findings of an important research stream on the meaningful role of universities for fostering innovation (Etzkowitz and Leydersdorff, 2000; Woerter, 2012; Bozeman et al., 2013; Breznitz and Feldman, 2013; Fukugawa, 2013). Specifically, the role of the university is analyzed in depth within the STI type of collaborations developed by firms (as opposed to other innovation agents such as technology centers and research excellence centers).

In particular, our hypotheses distinguish between a stronger impact of university collaborations on product innovation (2a) whilst the collaboration with other innovation agents (e.g. technology centers) is more likely to have a significant impact on process innovation (2b). This is likely to be due to the higher attention paid by universities to generate basic knowledge and radical innovations (typically around products) in contrast to technology centers (critical agent among 'other STI type of agents) that tend to focus on technological applications and process transformations.

Hypothesis 2a: Firms collaborating with universities are more likely to introduce product innovation than firms collaborating with other types of STI agents.

Hypothesis 2b: Firms collaborating with other types of STI agents are more likely to generate process innovations than those collaborating with universities.

3 Data and methodology

3.1 Database

We tested our hypotheses with firm-level data from the Spanish Technological Innovation Panel (PITEC). This panel survey is based on the Community Innovation Survey (CIS) and provides annual information on the innovation activities of a large sample of Spanish firms, allowing the study of how the changes in partnerships are related to the heterogeneity in innovation outputs over time. The data are collected by the Spanish National Institute of Statistics (INE), with the support of the Spanish

Foundation for Science and Technology (FECYT) and the Spanish Foundation for Technological Innovation (COTEC).

PITEC data are available from years 2003 to 2011 and include different profiles of firms.[2] Although we used data covering the whole period, our sample is restricted to firms from manufacturing and service sectors that responded to the panel survey for at least three consecutive years. Apart from that, we excluded observations from firms that have suffered sudden employment changes resulted from a merger or acquisition process, a high labor turnover, a layoff, or the impact of the crisis, among other reasons.

The resulting sample is composed of 4,969 firms over an average period of 7.1 years, which makes a total sample of 35,407 observations.

3.2 Measurement of variables

3.2.1 Dependent variables

Product innovation (Product) is a binary variable coded one (1) if the firm has introduced new or significantly improved products (i.e., goods or services) during the last three years (from *t-2* to *t0*), provided that such products were new to the market;[3] otherwise it takes value zero (0).

Process innovation (Process) is also binary and results from the combination of three variables. The first one indicates whether the firm has introduced new or significantly improved methods of producing goods or services. The second one indicates whether the firm has introduced new or significantly improved logistics, delivery or distribution methods. The third one indicates whether the firm has introduced new or significantly improved supporting activities for its processes, such as maintenance systems or operations for purchasing, accounting, and computing. If the firm has introduced at least one of these process innovations during the last three years this variable is coded one (1); otherwise it takes value zero (0).

3.2.2 Collaboration with STI and DUI partners

Partnerships linked to the *STI-mode of learning are* commonly identified by the use of scientific and technological knowledge that can be codified (Jensen et al., 2007). More specifically, this mode involves collaboration in R&D activities to generate new

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[2] The panel survey started in 2003 with a representative sample of firms with 200 or more employees, and an initial sample of firms with intramural R&D expenditures which was enlarged in 2004 and 2005 as a result of improvements in the identification of firms undertaking R&D activities. In 2004, the panel was expanded to include a sample of firms with less than 200 employees that reported external R&D expenditures but not intramural R&D expenditures, and a representative sample of firms with less than 200 employees that were not involved in any type of R&D activities. Overall, the panel has covered a sample of 12,828 Spanish firms over the period 2003-2011; however, some firms have dropped out from the sample because they have either disappeared (e.g., due to death, merger or acquisition), refused to continue collaborating, or been unreachable, among other reasons. Thus, the last collection of data (i.e. in 2011) corresponds to 10,074 firms.

[3] This excludes the simple resale of new goods or services, and changes of a solely aesthetic nature.

knowledge that usually serves to discover scientific and technological inventions, hence its prevalence in new and high technology industries (Isaksen and Karlsen, 2010). As in previous studies, we measured STI partnerships by means of the collaboration for innovation with at least one of the following partners: (1) consultants, private labs or R&D institutes; (2) universities or other higher education institutions; (3) public research centers; and (4) technology centers (Fitjar and Rodríguez-Pose, 2013). Since we are interested in the role of the university, we additionally distinguished between partnerships with universities or higher education institutions, and partnerships with others STI partners (i.e., consultants or private R&D labs and institutes, public research centers and technology centers).

In contrast, partnerships linked to the *DUI-mode of learning* are less research intensive. In this case, the collaboration among organizations is oriented to the development of knowledge through problem-solving and learning processes, which facilitate the exchange of experiences and know-how that cannot be easily written or codified (Jensen et al., 2007). This type of partnerships typically involves informal links beyond the boundaries of the firm that serve to transmit tacit knowledge (Lundvall, 1992). Similar to previous studies, we measured DUI partnerships as the collaboration for innovation with at least one of the following partners: (1) other firms from the same enterprise group, (2) suppliers of equipment, material, components or software; (3) customers; and (4) competitors or other firms from the same industry (Fitjar and Rodríguez-Pose, 2013).

By combining STI and DUI partnerships we created dummy variables that capture the different types of collaboration in which a firm can be involved. This is summarized in Table 1, according to which a firm may have no collaborations, collaborations with DUI partners only, collaborations with STI partners only, or collaborations with both STI and DUI partners. We identified firms with no collaborations as G0, while firms collaborating only with DUI partners are identified as G1. As mentioned before, we distinguished between collaborations with university and other STI partners. Thus, G2 are firms collaborating with universities only, while G3 are those collaborating with both DUI partners and universities. G4 are firms collaborating with other STI partners only, while G5 are those collaborating with both DUI partners and other STI partners. Those firms collaborating with both universities and other STI partners are identified as G6. Finally, firms collaborating simultaneously with DUI partners, universities and other STI partners are identified as G7. The reference category for the analysis is the group of firms that have no collaborations (G0).

[Insert Table 1 about here]

3.2.3 Control variables

We also added control variables for other factors that may influence a firm's innovation output and that have been commonly used in previous studies (Barge-Gil et al., 2011; Díaz-Díaz et al., 2008; Fitjar and Rodríguez-Pose, 2013; Grimpe and Sofka, 2009; Jensen et al., 2007). First, we controlled whether the firm has conducted in-house R&D

activities (*in-house R&D*). Second, we also controlled whether the firm has contracted external R&D activities (*external R&D*). Third, we controlled for the size of the firm which was measured by the total number of employees (*Firm's size*). Fourth, we control by the labor productivity level of the firm measured as sales in Euros per employee (*Productivity*).[4] Fifth, we controlled whether the ownership of the firm was participated by a foreign firm (*Foreign owned*). Sixth, we controlled whether the firm was exporter (*Exporter*). Seventh, given that innovation activities may differ between younger and older firms, the age of the firms is also added as control (*Firm's age*). Eighth, as innovation activities may be influenced by spillovers from other firms generating knowledge, we control whether the firm is located in a science park (*Science park*).

Table 2 provides the descriptive statistics and correlation matrix. Over the whole period of analysis, 32% of the sample has introduced a product innovation, and 58% introduced a process innovation.[5] Likewise, 57% has conducted in-house R&D activities, whereas 26% has hired external R&D services. On average, firms in the sample were large, with a staff of around 242 employees and a labor productivity of approximately 231,644 Euros. Likewise, 11% of the sample has been fully or partly owned by a foreign investor, and 63% has been exporters. Only 4% has been located in science or technology parks. Most of these variables are not highly correlated.

[Insert Table 2 about here]

3.3 Empirical model

Our hypotheses suggest that collaborations with partners linked to STI and DUI modes of learning influence the firm's innovation outcomes. Because innovations are not an immediate outcome of these and other inputs, we model binary indicators of product and process innovations as a function of the lagged the effects of the explanatory and control variables. Accordingly, the basic empirical model takes the following form:

$$Y^{*}_{i,t} = \beta X_{i,t\text{-}1} + \gamma Z_{i,t\text{-}1} + \alpha_i + u_{i,t} \qquad (1)$$

where the dependent variable

$$Y^{*}_{i,t} = \log\left[p(Y_{ij}=1)/\left(1-p(Y_{ij}=1)\right)\right] \qquad (2)$$

$$Y_{i,t} = \begin{cases} 1 \rightarrow \text{if the } i\text{-th firm has introduced a product/process innovation in year } t \\ 0 \rightarrow \text{otherwise.} \end{cases}$$

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[4] This variable was deflated at the aggregate division level of the NACE rev. 2 industry classification (GDP deflator, 2008=100).

[5] This high percentage of firms introducing innovations is due to the fact that the PITEC survey is mainly addressed to Spanish firms with innovation capabilities, which makes the sample proper for the analysis of innovation outcomes.

While i denotes the firm (i=1,…, n), t denotes the time period (t=1,…,T). X represents the vector of explanatory dummy variables for the k-1 different types of partnerships linked to STI and DUI modes of learning according to Table 1. Z represents the vector of control variables included in the model. Finally, α is the firm-specific intercept that controls for the fixed effects of the unobserved time-invariant variables, and u is an idiosyncratic disturbance term that changes across firms and time.

Apart from the fixed-effects estimation, we also run alternative specifications based on random-effects, but the Hausman's (1978) test provided evidence against the use of the random-effects estimation at the 0.001 level of significance for all estimated models. Therefore, the results reported here are from the fixed-effects estimation.

4 Results and discussion

The impact of collaborating with partners linked to STI and/or DUI modes of learning on the firm's product and process innovation is shown in Table 3 and Table 4, respectively. In both tables, Model 1 is the baseline fixed-effects logit estimation with control variables. Model 2 adds the explanatory variables measuring whether the firm collaborates with DUI partners only, STI partners only or both STI and DUI partners. Finally, Model 3 distinguishes collaborations with universities from collaborations with other STI partners.

4.1 The impact of STI and DUI partnerships on innovation types

[Insert Table 3 about here]

The results in Table 3 reveal that, in general, STI partnerships and DUI partnerships taken separately have a positive impact on product innovation (Model 2). In both cases the impact is statistically significant at the 0.01 level, meaning that, compared to firms that do not collaborate; those which collaborate with STI partners only or DUI partners only are more likely to introduce product innovations. More specifically, firms which in a given period collaborates with DUI partners only ($G1_{i,t-1}$) are around 20.1% - or 1.201 times - more likely to introduce a product innovation in the next period [exp(0.183) = 1.201]. Similarly, firms which in a given period collaborates with STI partners only ($G2_{i,t-1}$+$G4_{i,t-1}$+$G6_{i,t-1}$) are around 16.2% more likely to introduce a product innovation in the next year . A Wald test of simple and composite linear hypotheses suggests that the small difference between these types of partnerships is not statistically significant. In other words, collaborations with STI partners only contribute to product innovations as much as collaborations with DUI partners only.

The combination of STI and DUI partnerships has a positive impact on product innovation too, and this impact is statistically significant at the 0.001 level. In this case, a firm which in a given period collaborates with both STI and DUI partners ($G3_{i,t-1}$+$G5_{i,t-1}$+$G7_{i,t-1}$) is 49.0% more likely to introduce a product innovation in the next period. This contribution to product innovation is significantly higher than that of collaborating with STI partners only (*Prob.* > Chi^2 = 0.0001) or DUI partners only (*Prob.* > Chi^2 = 0.0012).

[Insert Table 4 about here]

The results exhibited in Table 4 show that STI partnerships and DUI partnerships also have a positive impact on process innovation that is statistically significant at the 0.001 level (Model 2). While firms collaborating with DUI partners only ($G1_{i,t-1}$) are 75.6% more likely to introduce process innovations than firms without any collaboration, those which collaborate with STI partners only ($G2_{i,t-1}+G4_{i,t-1}+G6_{i,t-1}$) are just 37.3% more likely to introduce process innovations. In this case, the impact of collaborations with DUI partners only is significantly higher than the impact of collaborations with STI partners only (*Prob.* > Chi^2 = 0.0014).

On the other hand, firms that in a given period collaborate for innovation with both STI and DUI partners ($G3_{i,t-1}+G5_{i,t-1}+G7_{i,t-1}$) are 62.1% more likely to introduce a process innovation in the next period. This effect is significantly higher than that of the collaboration with STI partners only (*Prob.* > Chi^2 = 0.0181), but it is not higher than that of the collaboration with DUI partners only. In the latter case, even though the difference is not statistically significant, the evidence found reinforces the importance of DUI partnerships for process innovations, and suggests that there are not complementarities between STI and DUI partnerships with regards to process innovation.

4.2 Partnerships with universities and other STI partners

When STI partnerships are separated into collaborations with universities only and collaborations with other STI partners, the results show that the former sub-type of partnership has no impact on product innovation while the latter does have an impact that is statistically significant at the 0.05 level (Model 3).Thus, compared to firms which do not collaborate, those which in a given period collaborate with other STI partners ($G4_{i,t-1}$) are 16.3% more likely to introduce a product innovation in the next period..

Interestingly, when a firm combines collaborations with universities and other STI partners the probability of introducing a product innovation increases. As the results indicate, firms that in a given period collaborate with both universities and other STI partners ($G6_{i,t-1}$) are 42.5% more likely to introduce a product innovation in the next period than those not collaborating for innovation. However, when collaborations with universities are combined with DUI partnerships ($G3_{i,t-1}$) the probability to introduce a product innovation is even higher, specifically 60.2% more likely. In contrast, firms collaborating with both DUI partners and other STI partners ($G5_{i,t-1}$) are just 33.8% more likely to introduce a product innovation in the next period. Finally, firms which simultaneously cooperate with DUI partners, universities and other STI partners ($G7_{i,t-1}$) are 66.5% more likely to introduce a product innovation.

According to these results, the collaboration with both DUI partners and universities seems to be more important for product innovation than the collaboration with both DUI and other STI partners excluding universities, but the difference between both types of partnerships is not statistically significant. However, coefficients $G5_{i,t-1}$ and $G7_{i,t-1}$ are significantly different (*Prob.* > Chi^2 = 0.0137), which means that the collaboration with universities in addition to other STI partners and DUI partners does improve the probability of product innovation.

The distinction between universities ($G2_{i,t-1}$) and the rest of STI partners ($G4_{i,t-1}$) also shows that separately both types of collaborations increase the likelihood of introducing a process innovation up to 46,1% and 42,8%, respectively (Model 3). In both cases the impact is significant at the 0.001 level. However, the contribution of DUI partnerships to process innovation is still significantly higher than that of cooperating with universities only (*Prob.* > Chi^2 = 0.093) and that of cooperating with other STI partners only (*Prob.* > Chi^2 = 0.0247).

The results also reveal that the capability to innovate in processes is notably influenced by the combination of DUI and other STI partners, excluding universities. More specifically, firms that in a given period cooperate for innovation with both DUI partners and other STI partners ($G5_{i,t-1}$) are 88.7% more likely to introduce a process innovation in the next period. In contrast, firms that cooperate with both DUI partners and universities in a given period ($G3_{i,t-1}$) are just 21.8% more likely to introduce a process innovation in the next period, , while firms that simultaneously cooperate with DUI partners, universities and other STI partners ($G7_{i,t-1}$) are 53.7% more likely to introduce a process innovation.

The contribution of collaborating with both DUI partners and other STI partners is significantly higher than that of collaborating with both DUI partners and universities (*Prob.* > Chi^2 = 0.0013), and that of collaborating simultaneously with DUI partners, universities and other STI partners (*Prob.* > Chi^2 = 0.0516). However, it is not significantly higher than collaborating with DUI partners only.

4.3 Discussion of findings

In summary, our results confirm that collaborative agreements, either with partners linked to the STI-mode of learning or partners linked to the DUI-mode of learning taken separately, influence positively product and process innovation. This finding supports our hypothesis H1a, but interestingly it is worth to mention that we found a stronger impact of DUI partnerships on process innovation. In line with this, Fitjar and Rodríguez-Pose (2013) found that collaborations with suppliers - a type of DUI partner - specially influence process innovations. According to our results, the simultaneous combination of DUI and STI partnerships, rather than only one or another type of partnership, is linked to a higher probability of product innovation. This is also consistent with previous studies (Jensen et al., 2007). Nonetheless, the combination of both types of partnerships does not add relevant value on process innovation according to our results. Consequently, Hypothesis 1c is partially accepted.

Another finding connected to our hypotheses is that firms relying on collaborations with universities in combination with DUI partnerships, are more likely to introduce product innovations, and this provides evidence supporting our hypothesis H2a. The basic knowledge provided by universities and other higher education institutes must fit the needs of customers and has to be contrasted with competitors, suppliers and other firms from the same enterprise group in order to successfully create new products. Thus, contrary to previous studies which suggest that firms collaborating with universities should assign less importance to external relationships (Bargel-Gil et al., 2011), we argue that it is important to collaborate with universities for product innovation together with partners traditionally linked to the DUI-mode of learning.

Conversely, the results also show that firms relying on collaborations with other STI partners in combination with DUI partners are more likely to introduce process innovation, which in this case provides evidence supporting our hypotheses H2b. The orientation of other STI partners different from universities (i.e., private labs or R&D institutes, as well as technology centers) is focused on application of knowledge, what in most cases helps firms improve existing processes to gain efficiency. Indeed, according to the extant literature, collaboration with universities has been found to be closely related to the likelihood of product innovation; however, collaboration with other STI partners, such as research institutes, has been found to be related to process innovation (Fitjar and Rodriguez-Pose, 2013).

4.4 Robustness checks

Fixed-effects models are designed to study within-subject variability. For instance, we have analyzed how within-firm variability in STI/DUI partnerships affects within-firm variability in product/process innovation. One limitation of these models, particularly fixed-effects logit models, is that they do not work well with data for which within-subject variation is minimal or for variables that change slowly over time. Given that the introduction of innovations is a rare behavior among most firms, many observations from our dependent variables remain invariant over the whole period of analysis. Observations from firms that do not innovate during the whole period, as well as observations from firms that innovate in every year are automatically dropped from the analysis. As a consequence, the final sample used in the present study was substantially reduced. Without this restriction, the final sample would have been 64,556 observations (instead of 35,407) corresponding to 9,084 firms (instead of 4,969).

In order to confirm that our results are robust to the fixed-effects model specification, and that they do not depend on potential systematic differences between the final sample and the sample with omitted observations, we estimated the empirical model using separate logit regressions for each year. Additionally, we also estimated the empirical model using random-effects logit estimation. In both analyses, we added controls for the industry, while in the random-effects models we also added dummies for each year.[6]

In most years, the results from cross-sectional logit regressions are similar to those obtained from the fixed-effects estimations. Furthermore, the analysis based on random-

[6] The analyses are available from the authors upon request.

effects logit estimations confirms our results too, though in this case the coefficients are somewhat larger. Coefficients from both logit regressions and random-effects logit estimations not only have signs and significance levels similar to those from fixed-effects logit estimations, but the differences between the coefficients used for hypothesis testing were also significant, what makes us reach similar conclusions.

5 Conclusion and implications

There seems to be no consensus on the drivers of innovation, neither on the impact of innovation on firm performance (Evangelista and Vezzani, 2010; Hemert et al., 2012). We have investigated the relationships among different components of the "innovation black box", namely the STI and DUI learning modes, research based collaborative agreements, and innovation output. We believe that our exploratory findings add new insights to the field of learning modes and the role played by entrepreneurial universities in enhancing innovation and value creation.

Firstly, we have shown that reconciling STI and DUI learning modes is a complex but rewarding task. STI and DUI practices do not only rely on firm internal activities, but also on firm external collaboration. Companies are more likely to undertake product-innovation strategies when STI and DUI (internal and external) practices are simultaneously handled within an organization. Secondly, STI and DUI exert separately a positive effect on innovation, which supports previous findings in the literature. But the magnitude of each effect STI or DUI varies for each type of innovation (i.e., product and process innovation). More specifically, the separate influence of DUI on process innovation is more pronounced than that of STI. Our results confirm, to some extent, other findings of the literature (Jensen et al., 2007). Thirdly, firms which collaborate with universities are more likely to innovate, but universities cannot be their only partners. Firms need to cooperate with other stakeholders while they interact with universities. Lastly, most empirical studies have analyzed this phenomenon from a static perspective. We have applied a multi-period approach by using a large longitudinal data set and conducting panel regression tests in order to verify the relationships among STI and DUI learning modes, collaborative agreements and product/process innovation over time.

Our work is not exempt of limitations. We have used dichotomous variables describing learning modes (STI, DUI) and two types of innovation (product and process innovation). The availability of a larger number of continuous variables would refine the measurement used in this study. Although we believe that the meaning and significance of our results would not change much, the use of continuous variables can provide a more accurate measure of the intensity of the analyzed concepts. In addition, the use of more carefully refined STI-DUI variables and the application of a longer time span for capturing the dynamics of innovation would add robustness to our results.

Despite the shortcomings mentioned earlier, we can provide at least two relevant policy implications. On the one hand, policy makers should recognize that innovation benefits come from both product differentiation and cost efficiencies. Not only product innovation is important, but also process innovation contributes to value creation. Most policy actions have fostered programs designed to improve the STI capacity of firms (i.e., particularly SMEs), neglecting the relevance of the DUI approach discussed in our paper. Company owners and managers can be more effective in capitalizing their innovation efforts when they interact not only with scientists, but also customers, suppliers, competitors, end-users of their products, and other many stakeholders (e.g., government authorities, NGOs). The STI and DUI learning approaches are important, but undertaking both together makes firms more likely to achieve innovation outputs. On the other hand, there is a need to better understand the role played by entrepreneurial universities in the process of value creation (González-Pernía et al., 2013). Firms that collaborate with universities are more likely to innovate in product, but they need to expand their collaborative network of partners to transform their ideas into marketable products. This means that universities are valuable partners for the generation of new ideas, but this is not enough to successfully innovate. Other partners are needed for transferring knowledge to the marketplace.

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Tables

Table 1. Groups from the combination of STI and DUI partnerships

<table>
<tr><td colspan="2">o</td><td colspan="2">Collaboration with DUI partners: No</td><td colspan="2">Collaboration with DUI partners: Yes</td></tr>
<tr><td>Collaboration with other STI partners: No</td><td>Collaboration with universities: No</td><td>No collaboration</td><td>G0</td><td>DUI partners only</td><td>G1</td></tr>
<tr><td>Collaboration with other STI partners: No</td><td>Collaboration with universities: Yes</td><td rowspan="3">STI partners only</td><td>G2</td><td rowspan="3">Both STI & DUI partners</td><td>G3</td></tr>
<tr><td>Collaboration with other STI partners: Yes</td><td>Collaboration with universities: No</td><td>G4</td><td>G5</td></tr>
<tr><td>Collaboration with other STI partners: Yes</td><td>Collaboration with universities: Yes</td><td>G6</td><td>G7</td></tr>
</table>

Table 2. Descriptive statistics and correlation matrix

Variable		Obs.	N	Mean	S.D.	Min	Max	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
(1)	Product innovation$_{i,t}$	35,407	4,969	0.32	0.47	0.00	1.00	1.00									
(2)	Process innovation$_{i,t}$	35,407	4,969	0.58	0.49	0.00	1.00	0.16	1.00								
(3)	In-house R&D$_{i,t-1}$	35,407	4,969	0.57	0.49	0.00	1.00	0.34	0.17	1.00							
(4)	External R&D$_{i,t-1}$	35,407	4,969	0.26	0.44	0.00	1.00	0.19	0.11	0.33	1.00						
(5)	Firm's size$_{i,t-1}$	35,407	4,969	241.98	1,284.41	1.00	41,509.00	-0.04	0.04	-0.11	0.00	1.00					
(6)	Productivity$_{i,t-1}$	35,407	4,969	231,644.80	917,287.90	0.01	1.23×10^8	0.02	0.05	0.01	0.07	0.18	1.00				
(7)	Foreign owned$_{i,t-1}$	35,407	4,969	0.11	0.31	0.00	1.00	0.02	0.01	-0.04	0.00	0.29	0.22	1.00			
(8)	Exporter$_{i,t-1}$	35,407	4,969	0.63	0.48	0.00	1.00	0.13	0.07	0.18	0.12	0.10	0.29	0.14	1.00		
(9)	Firm's age$_{i,t}$	35,407	4,969	24.49	19.92	1.00	342.00	-0.04	0.03	-0.06	0.00	0.33	0.20	0.09	0.12	1.00	
(10)	Science park$_{i,t-1}$	35,407	4,969	0.04	0.20	0.00	1.00	0.07	0.01	0.10	0.09	-0.06	-0.10	-0.05	-0.04	-0.11	1.00

Table 3: Fixed effects logit estimation predicting the introduction of product innovations

	(1)	**(2)**	**(3)**
In-house R&D$_{i,t-1}$	0.854*** (0.045)	0.822*** (0.045)	0.820*** (0.045)
External R&D $_{i,t-1}$	0.214*** (0.038)	0.170*** (0.038)	0.169*** (0.038)
Ln(Firm's size$_{i,t-1}$)	0.374*** (0.052)	0.360*** (0.052)	0.356*** (0.052)
Ln(Productivity$_{i,t-1}$)	0.053† (0.029)	0.051† (0.029)	0.052† (0.029)
Foreign owned$_{i,t-1}$	-0.064 (0.097)	-0.065 (0.097)	-0.066 (0.097)
Exporter$_{i,t-1}$	0.120* (0.054)	0.108* (0.054)	0.108* (0.055)
Firm's age$_{i,t}$	-0.025*** (0.006)	-0.028*** (0.006)	-0.029*** (0.006)
Science park$_{i,t-1}$	0.152 (0.167)	0.126 (0.168)	0.125 (0.169)
G1$_{i,t-1}$: DUI partners only		0.183** (0.056)	0.183** (0.056)
G2$_{i,t-1}$+G4$_{i,t-1}$+G6$_{i,t-1}$: STI partners only		0.150** (0.056)	
G3$_{i,t-1}$+G5$_{i,t-1}$+G7$_{i,t-1}$: Both DUI&STI partners		0.399*** (0.053)	
G2$_{i,t-1}$: University partners only			0.025 (0.091)
G3$_{i,t-1}$: DUI & University partners (excluding cooperation with other STI partners)			0.471*** (0.107)
G4$_{i,t-1}$: Other STI partners only			0.151* (0.075)
G5$_{i,t-1}$: DUI & other STI partners (excluding cooperation with universities)			0.291*** (0.071)
G6$_{i,t-1}$: Universities & other STI partners (excluding cooperation with DUI partners)			0.354*** (0.103)
G7$_{i,t-1}$: DUI, Universities & other STI partners			0.510*** (0.072)
Number of firms	4,257	4,257	4,257
Number of observations	30,563	30,563	30,563
Model fit statistics:			
Deviance (-2*log likelyhood)	23,634.55	23,575.28	23,562.43
Deviance difference		59.28***	12.85*

Notes: Standard errors in parentheses. Level of statistical significance: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, † $p \leq 0.1$

Table 4: Fixed effects logit estimation predicting the introduction of process innovations

	(1)	(2)	(3)
In-house R&D$_{i,t-1}$	0.823*** (0.040)	0.774*** (0.041)	0.773*** (0.041)
External R&D $_{i,t-1}$	0.370*** (0.040)	0.309*** (0.040)	0.310*** (0.040)
Ln(Firm's size$_{i,t-1}$)	0.737*** (0.048)	0.722*** (0.048)	0.724*** (0.048)
Ln(Productivity$_{i,t-1}$)	0.133*** (0.028)	0.129*** (0.028)	0.129*** (0.028)
Foreign owned$_{i,t-1}$	0.030 (0.090)	0.030 (0.090)	0.031 (0.090)
Exporter$_{i,t-1}$	0.161** (0.050)	0.149** (0.050)	0.148** (0.050)
Firm's age$_{i,t}$	0.008 (0.006)	0.007 (0.006)	0.007 (0.006)
Science park$_{i,t-1}$	-0.039 (0.171)	-0.069 (0.172)	-0.079 (0.172)
G1$_{i,t-1}$: DUI partners only		0.563*** (0.058)	0.563*** (0.058)
G2$_{i,t-1}$+G4$_{i,t-1}$+G6$_{i,t-1}$: STI partners only		0.317*** (0.058)	
G3$_{i,t-1}$+G5$_{i,t-1}$+G7$_{i,t-1}$: Both DUI&STI partners		0.483*** (0.059)	
G2$_{i,t-1}$: University partners only			0.379*** (0.097)
G3$_{i,t-1}$: DUI & University partners (excluding cooperation with other STI partners)			0.197† (0.115)
G4$_{i,t-1}$: Other STI partners only			0.356*** (0.077)
G5$_{i,t-1}$: DUI & other STI partners (excluding cooperation with universities)			0.635*** (0.083)
G6$_{i,t-1}$: Universities & other STI partners (excluding cooperation with DUI partners)			0.108 (0.110)
G7$_{i,t-1}$: DUI, Universities & other STI partners			0.430*** (0.083)
Number of firms	4,969	4,969	4,969
Number of observations	35,407	35,407	35,407
Model fit statistics:			
Deviance (-2*log likelyhood)	26,874.55	26,727.51	26,712.07
Deviance difference		147.04***	15.44*

Notes: Standard errors in parentheses. Level of statistical significance: *** $p \leq 0.001$, ** $p \leq 0.01$, * $p \leq 0.05$, † $p \leq 0.1$