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The effect of population size and technological collaboration on firms' innovation

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ABSTRACT

In the current knowledge economy, firms hardly innovate alone; the collaboration with other partners has become crucial for successful innovation. Literature has recently focused on two modes of collaboration: the learning-by-doing, by-using and by-interacting (DUI) and science and technology-based innovation (STI). Nevertheless, collaboration seems to be easier if firms are located in highly populated areas. This paper aims to analyse whether the population size of municipalities where firms are located influences firm innovation either in a direct way or by shaping the effect of the DUI and STI partnerships. Applying panel data methodology to a sample of 3004 Spanish manufacturing firms over the period 2009 to 2016, the results show that innovative performance benefits from STI and DUI innovation modes, especially product innovation. In contrast, location in less populated municipalities seems to have no effect on innovation, regardless of the threshold used to limit the number of inhabitants. Also, weak evidence of the moderating role of the population size on the effect of DUI and STI partnerships on firm innovation is found.

1. Introduction

Firms rarely innovate alone, but look for the collaboration with other agents who can be stakeholders involved in the business process or experts in innovation research (Chen et al., 2011). Partnerships with stakeholders (i.e., customers, suppliers, competitors) are usually implicitly developed as a consequence of the business process and based on tacit exchanges of knowledge, whereas collaboration with specialized innovation agents (i.e., universities or research centres) often involves a formal pattern of innovation not necessarily connected with the traditional business process (Aslesen et al., 2012). In a very enlightening paper, Jensen et al. (2007) group these collaborative patterns in two modes of learning: learning-by-doing, by-using, and by-interacting (DUI) and science and technology-based innovation (STI), which respectively encompass collaborative innovation with business stakeholders and specialized innovation agents. In recent years, a bunch of studies have examined the relationship between DUI and STI modes of learning and firms' innovation (Fitjar and Rodríguez-Pose, 2013; González-Pernía et al., 2015; Parrilli and Alcalde-Heras, 2016; Parrilli and Radicic, 2021; Hervas-Oliver et al., 2021; Mathew and Paily, 2021). However, although there is a consensus about the distinction between STI and DUI modes, the effect of these patterns and the drivers and actors involved on a firm's innovation remains unclear (Santos et al., 2021).

Since Audretsch and Feldman (2004) noted the importance of the localization of firms on the innovation performance of a region, an extensive amount of research has studied the differences in firm innovation performance across regions (Naz et al., 2015) in the stream of the literature on urbanization economies, which studies the scale effects associated with city or density size (Feldman, 1999). Innovation and R&D activities are usually more geographically concentrated than manufacturing (Audretsch and Feldman, 1996; Carlino et al., 2012). In this sense, urban agglomerations play a relevant role in enabling firms' capacity to innovate, especially if they rely on the same science-base to innovate (Feldman and Audretsch, 1995) or if there is a quality university in the local area that can enhance the effectiveness of the firms' R&D (Chen et al., 2021). The core arguments behind this approach rely on better access to innovative facilities (Feldman and Florida, 1994; Patterson and Anderson, 2003) and greater ease of knowledge exchange due to the physical proximity of the agents (Wixe, 2018; Chen et al., 2021). Nevertheless, recent studies have evidenced that firms in less populated regions can also be innovative if they count on other

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endowments or have access to innovation resources (Rychen and Zimmermann, 2008; Eder, 2019). Thus, research on the differences in the innovative behaviour of firms located in more or less populated municipalities remains fragmented (Eder, 2019) and the results are somehow inconclusive.

Previous literature mostly provides evidence that firms located in less populated territories have more difficulties accessing to DUI and STI innovation modes (McPherson et al., 2001; Cooke, 2002; Fitjar and Rodríguez-Pose, 2013; Florida et al., 2017; Reidolf and Graffenberger, 2019; Chen et al., 2021). However, the extent to which population size may affect the relationship between DUI and STI partnerships and innovation has not been analysed.

The goals of this paper are twofold. Firstly, it aims to explore the influence of the DUI and STI partnerships and the population size of the municipality where the firm is located on its innovative performance. Secondly, it seeks to analyse whether these potential effects of DUI and STI innovation modes are moderated by the size of the municipality. To this end, panel data methodology is applied to a sample of 3004 Spanish manufacturing firms over the period 2009 to 2016.

This study contributes to the literature in several ways. First, it extends the literature on the geography of innovation by focusing on the role played by the population size of the municipalities where firms are located. More specifically, this paper explores separately the direct effect of this factor on firm innovative performance and the moderating role it can play by shaping the influence of DUI and STI innovation modes. Second, by applying panel data methodology, the longitudinal nature of the data (2009–2016) is considered, which allows capturing the current nature of firms' innovation activities and population trends, both of which are inherently dynamic processes. Finally, the study of a country characterized by non-proactive-to-innovation behaviour can offer different findings, compared with other studies based on traditionally innovative countries (Parrilli and Radicic, 2021). Gaining a better understanding of whether the number of inhabitants of a municipality shapes the relationship between companies' technological collaborations and innovation outcomes is critical in countries like Spain.

The remainder of the paper proceeds as follows: Section 2 introduces the theoretical framework and the research hypotheses; in Section 3, the data and strategy of estimation are described; in Section 4, the empirical results are discussed, and finally, in Section 5, the concluding remarks are provided, as well as implications for literature and practice.

2. Theoretical framework

2.1. DUI and STI innovation modes

Previous research in the innovation behaviour of organizations shows that collaboration with external agents lets firms, especially small firms, take advantage of each other's knowledge (Rodríguez-Gulías et al., 2020). Agglomeration of firms often facilitates the rapid dissemination of knowledge through the clusters of firms located in the same place (Pinch et al., 2003). The firms most interested in forming geographical clusters tend to be those with the weakest technologies or scarcity of human capital, training programs, suppliers or distributors (Myles Shaver and Flyer, 2000). However, collaboration with equals is not the only way of gaining knowledge for innovation; firms can complement peer-collaboration with other alliances with business stakeholders (i.e., customers, suppliers, competitors) and with specialized innovation agents (such as public research centres, universities, technology centres, and research laboratories). According to Jensen et al. (2007), firms use two modes of learning for innovation: learning-by-doing, by-using and by-interacting (DUI), when collaborating with business stakeholders, and science and technology-based innovation (STI), when collaborating with specialized innovation agents.

Collaborations based on the DUI mode of innovation allow firms to "apply" tacit knowledge into new industrial designs and business models, especially in the manufacturing industry (Asheim and Coenen, 2005), enhancing innovations arising from the stakeholder interactions in business process (González-Pernía et al., 2015). In contrast, collaborations based on the STI mode contribute to "creating" scientific and technological knowledge, not only for the firm responsible for these collaborations but also for other firms, especially through new product innovations (Chen et al., 2011; Fitjar and Rodríguez-Pose, 2013). Moreover, firms can combine DUI and STI modes, taking advantage of the advances in scientific knowledge in product innovation and of the exchanges and interactions with customers, suppliers, and competitors for process innovation (González-Pernía et al., 2015).

Due to the increasing interest in how DUI and STI learning modes can influence firms' innovation activities, in recent years a bunch of studies have intensively researched this relationship. Thus, by assuming the open innovation paradigm that no company owns all technological resources to innovate, Chen et al. (2011) conclude that DUI and STI modes let firms increase their innovation outcomes. More specifically, these authors find that the number and diversity of DUI partnerships are positively related to innovation performance. In turn, the number and diversity of STI partnerships hold an inverted U-shaped relationship with innovation performance, and they are related to high-tech and competitive environments. According to Chen et al. (2011), the STI mode relates to radical innovations and is based on a previous investment in internal R&D. Thus, the knowledge developed through internal R&D investments increases the firm's absorptive capacity to assess the potential of external knowledge, which has to be applied to the creation of new products.

Regarding innovation types, Fitjar and Rodríguez-Pose (2013) find that, although the DUI and STI modes benefit product and process innovation, different types of partnerships are related to different types of innovation. Using a sample of firms located in the five largest urban agglomerations in Norway, the authors evidence that the STI mode is strongly related to product innovation, especially radical product innovation. The DUI cooperation with customers is also positively related to product innovation, and the DUI mode developed through collaboration with suppliers is related to product and especially process innovation. In contrast, the DUI cooperation with competitors is negatively related to firm innovative performance.

Following a similar approach, González-Pernía et al. (2015) conclude that whereas process innovation seems to be more influenced by the DUI mode of learning, the combination of STI and DUI modes benefits more product innovation. In particular, collaboration with universities only benefits product innovation when it is combined with other STI agents.

In this line, Parrilli and Alcalde-Heras (2016) confirm the stronger impact of the combined DUI-STI modes on technological innovation, compared to the individual effects of each one of them, also considering the global and regional geographical scope of collaboration. According to these authors, the STI mode has a higher effect for technological (new products and manufacturing processes) and radical innovations (new products for firm and for the market) than DUI mode, especially at the regional level. For non-technological innovations (marketing and organizational innovations), the DUI mode has more global impact than the STI mode. At the regional level, the STI mode counts as much as DUI-global mode.

At a country level of analysis, Hervas-Oliver et al. (2021) find that firms located in catching-up countries take advantage of the STI learning mode mainly for product innovation and the DUI modes for process innovation, in line with previous studies. Additionally, small firms located in advanced countries are more innovative because they get higher returns from both learning modes than firms located in catching-up countries, which are more dependent on DUI collaborations for process innovations than STI collaborations.

The literature has also tested the extent to which the relationship between DUI and STI partnerships and innovative performance may depend on firm size. Thus, Mathew and Paily (2021) provide evidence that small firms take advantage of the DUI mode, whereas large firms benefit from both STI and DUI modes. This result is similar to that of Hervas-Oliver et al. (2021), who state that the effectiveness of R&D collaboration between firms is linked to previous investment in internal R&D, and large firms are favoured by this factor. Parrilli and Radicic (2021) also find that the innovative performance of large and medium-sized firms benefits more from the STI and DUI modes than that of small and micro enterprises, but only when considering internal knowledge exchanges (internal staff in the DUI mode and internal R&D in the STI mode). In turn, compared to large firms, medium-sized firms have a higher capacity to exploit the DUI and STI interactions with external partners (customers, suppliers in the DUI mode, and universities in the STI mode).

According to the previous literature review, we state the following hypotheses:

H1. Firms collaborating are more likely to innovate.

H1a. Firms collaborating with customers, suppliers, and competitors (DUI mode) are more likely to innovate.

H1b. Firms collaborating with universities (STI mode) are more likely to innovate.

2.2. Population size and firm innovation

Urban agglomeration is traditionally connected with firms' propensity to innovate and the formation of clusters for innovation and R&D activities (Audretsch and Feldman, 1996; Carlino et al., 2012). Previous literature provides evidence that a city's size or density becomes a relevant variable in explaining firms' propensity to innovate (Feldman and Audretsch, 1999; Carlino et al., 2009; Chen et al., 2021). The arguments underlying this approach are that firms located in highly populated territories have better access to innovation facilities (Feldman and Florida, 1994; Patterson and Anderson, 2003) and increase the effectiveness of R&D investments and collaborations (Chen et al., 2021), as a consequence of the higher pressure from competitors and customers (Mateut, 2018), compared to firms located in less populated territories. Consistent with these arguments, from a regional innovation approach, it has also been acknowledged that densely-populated regions favour the proximity of organizations, which facilitates the dissemination of knowledge and the absorptive capacity of these firms (Pinch et al., 2003). Peripheral and less populated areas, in contrast, fail to offer similar facilities for knowledge exchange, and this limits the absorptive capacities of firms (Wixe, 2018; Chen et al., 2021).

However, in recent years some studies have offered an alternative perspective, evidencing that firms in low densely populated and peripheral areas can also be innovative if they count on other endowments or have temporary access to innovation resources (Rychen and Zimmermann, 2008; Eder, 2019). Moreover, organizations located in less populated areas can take advantage of their lower structural costs for developing specialized poles of innovation (Tödtling and Trippl, 2018). Indeed, firms located in rural regions could be as competitive as those located in more populated urban areas if they have access to qualified human capital and public and private R&D resources (García-Alvarez-Coque et al., 2012). Following this approach, those peripheral regions that host a university can provide similar resources for innovation as more populated areas (Eder, 2019).

Finally, the effect of population size on product and process innovation is closely related to the firms' capacity to collaborate with all agents of the innovation system (Copus and Skuras, 2006). Thus, Kasabov (2011) finds that the failure of product innovation of biotechnological clusters happens when the firms lack the capacity to establish competitive links with local research groups and qualified managers. Similarly, Mateut (2018) concludes that firms in highly populated cities are more likely to innovate because of the competitive pressure coming from local competitors and customers. In contrast, Capitanio et al. (2010) indicate that the location in less populated areas favours product and process innovation of agri-food firms. Despite these initial findings, there is no robust evidence supporting the population size effect on product and process innovation (Peón and Martínez-Filgueira, 2020).

Based on the previous literature review, the following hypothesis is proposed:

H2. Firms in more populated municipalities are more likely to innovate.

2.3. DUI and STI learning modes and firm innovation: the role of population size

Previous literature suggests that firms in less populated areas have fewer opportunities to access local innovation resources coming from specialized research institutions, as well as more limitations to collaborate with customers, suppliers, or competitors (Audretsch, 1988; Patterson and Anderson, 2003; Davies et al., 2012; Isaksen and Karlsen, 2016; Laurin et al., 2020; Kluza, 2020).

Thus, concerning STI mode of innovation, the main disadvantages of less populated territories are the lack of R&D facilities that encourage knowledge exchange, as well as less-diverse human capital (Feldman and Florida, 1994; Florida et al., 2017). Indeed, Chen et al. (2021) show that firms in densely populated cities of 25 Asian countries increase the effectiveness of R&D investments through their linkages with local high-quality universities.

In contrast, firms located in less populated areas are less likely to collaborate with similar firms than those located in more populated areas (DUI mode). Thus, firms in larger cities are better positioned than those ones in rural areas, thanks to a better access to customers and suppliers and lower transport costs (Patterson and Anderson, 2003). The distance to more populated areas influences the contact with customers, who can provide new ideas for product or process innovation (Julien, 2007). It is often the case that there are more differences in innovation between urban and remote rural regions than between urban centres and more centrally located rural regions (Laurin et al., 2020).

The above-mentioned evidence shows that access to DUI and STI partnerships with geographically proximate actors is more difficult for firms located in less populated areas. At the same time, the research indicates that collaborative innovation is essential in such firms to overcome the fact that knowledge sharing does not occur tacitly with nearby players. In other words, technological collaboration has become a cornerstone for overcoming the limited absorptive capacity of firms located in peripheral and less populated areas (Cooke, 2002; Oughton et al., 2002; García-Cortijo et al., 2019). Additionally, the difficulty of collaborating with the a priori few similar actors can encourage firms to do it with non-similar actors (McPherson et al., 2001; Reidolf and Graffenberger, 2019) such as specialized innovation agents.

In a similar vein, Wixe (2018) and Eder (2019) highlight that diversity in education and the possibility to manage knowledge-based collaborations with STI partners become especially relevant for the sustainability of firms in less populated territories. Also, Parrilli and Alcalde-Heras (2016) indicate that firms in less populated areas are less likely to get innovative ideas for new products from DUI stakeholders than from STI collaboration with universities, which are knowledge providers that offer partnerships supported by explicit technological knowledge. In contrast, Fritsch and Wyrwich (2021) do not find that DUI and STI partnerships are affected by the population size of the firm's location. Their findings show that German firms located in less populated territories can access STI and DUI modes through a decentralized political and financial structure, and easy access to universities, which have a strong orientation toward the commercial application of knowledge, and collaboration with other stakeholders scattered throughout the territory.

After reviewing previous literature, it seems that the (product and process) innovation of collaborating firms (or technological collaborators), benefits from their location in more populated areas; yet it is expected that the STI mode will be more influential for innovative outcomes than the DUI mode in less populated municipalities. In other words, we propose that the size, in terms of population, of the municipality where the firm is located shapes the relationship between the DUI and STI modes and firm innovative performance.

H3. Technological collaborators in more populated municipalities are more likely to innovate than their counterparts in less populated municipalities.

3. Methodology

This section introduces the sample, the variables, and the estimation models used in the analysis.

3.1. Database and sample

The information used in this work comes from the Spanish Survey of Business Strategy (SSBS), a yearly survey covering a wide range of firms operating in all manufacturing industries. More specifically, the SSBS covers a random sample of small firms (between 10 and 200 employees) and a detailed sample of large firms (>200 employees). The information for each company includes economic/financial, and innovation data. Initially, the sample consisted of an unbalanced panel of 3004 Spanish manufacturing companies observed between 2009 and 2016.

$$\text{logit}\{Pr(\text{INNO}_{it}=1)\} = \beta_0 + \beta_1\,\text{LNAGE}_{it} + \beta_2\,\text{LNEMP}_{it} + \beta_3\,\text{HIGHTECH}_{it} + \beta_4\,\text{RD\_SALES}_{it} + \beta_5\,\text{POPSIZE}_{it} + \beta_6\,\text{COLLABORATION}_{it} + \nu_i$$

3.2. Definition and measurements of the variables

The innovative performance of firms is measured through product innovation and process innovation. Thus, we use two dummy variables that take the value of 1 when a firm reports having "obtained product innovations (completely new products or with important modifications that make them different from those that had been produced before)" (INNOPROD)/"introduced some modification important in the process of production and/or distribution (INNOPROC)" in the current year.[1]

The key explanatory variables regarding the STI and DUI innovation modes are four dummy variables that indicate whether the company reports having had technological collaboration with: customers (CUSTOMERS), competitors (COMPETITORS), suppliers (SUPPLIERS) or universities and/or technology centres (UNIVERSITIES). The last variable refers to the STI mode, while the rest refers to the DUI mode.

In turn, the independent variable of interest concerning the population size is constructed as a dummy variable (POPSIZE) that takes the value of 1 if the company is located in a municipality with fewer than 50,000 inhabitants and 0 otherwise; 50,000 inhabitants has been selected as the "starting threshold" because universities tend to be located near municipalities with a minimum number of inhabitants that allows them to survive. Additionally, we consider two binary variables in order to test if the findings are robust to alternative definitions of the population size of the firm's municipality. Specifically, we employ the thresholds of 10,000 and 2000 inhabitants.

Finally, four control variables are included. Firm age (LNAGE) is often mentioned as a proxy for business experience. Firm size (LNEMP) is measured by the number of employees. Both variables are expressed in logarithmic form. The firm's R&D intensity is included as the ratio of R&D expenditures to sales (RD_SALES). Besides, industry-specific characteristics are also considered through a dummy for companies in the high-medium technology sectors according to the Eurostat classification[2] (HIGHTECH) (EUROSTAT, 2022).

Table 1 summarizes the definition of dependent, independent and control variables.

3.3. Strategy of estimation and model specification

We used random-effects panel data *logit* regressions to test the proposed hypotheses, as both dependent variables are dummies.

The strategy of estimation was designed in two steps. In the first step, we explored the direct effect of DUI and STI innovation modes and the population size on the probability of having (product or process) innovation (Hypotheses 1 and 2). More specifically, we defined the following baseline model (Model 1):

where INNO_{it} is the observed product or process innovation for occasion *i* in the firm *j*, β_0 is the constant and ν_i is the individual-specific random effect. In turn, $\text{COLLABORATION}_{it}$ represents the four explanatory variables referred to different types of partnerships associated with DUI and STI learning modes (CUSTOMERS_{it}, COMPETITORS_{it}, SUPPLIERS_{it}, and UNIVERSITIES_{it}), alternatively introduced in the specifications, resulting in four alternative specifications (Model 1.1 to Model 1.4).

In the second step, each of the four variables referred to DUI and STI innovation modes interacted with the population size variable to study how the number of inhabitants in the municipality where the firm is located could shape the effects of technological collaboration with different agents on firm innovative performance (Hypothesis 3). Accordingly, the following model is specified (Model 2):

$$\text{logit}\{Pr(\text{INNO}_{it}=1)\} = \beta_0 + \beta_1\,\text{LNAGE}_{it} + \beta_2\,\text{LNEMP}_{it} + \beta_3\,\text{HIGHTECH}_{it} + \beta_4\,\text{RD\_SALES}_{it} + \beta_5\,\text{POPSIZE}_{it} + \beta_6\,\text{COLLABORATION}_{it} + \beta_7\,\text{POPSIZE}_{it}\text{xCOLLABORATION}_{it} + \nu_i$$

where $\text{POPSIZE}_{it}\text{xCOLLABORATION}_{it}$ represents the four interaction terms. These terms allow one to test the null hypothesis that the estimated coefficients of technological collaborators for firms located in less populated municipalities are equal to the estimated coefficients for their counterparts in more populated municipalities.

[1] The complete questionnaire is available here (only in Spanish): https://www.fundacionsepi.es/investigacion/esee/en/svariables/disponibles.asp.

[2] Eurostat uses the aggregation of the manufacturing industry according to technological intensity and based on the NACE Rev.2 at the two-digit level.

Table 1
Definitions of dependent, control and independent variables.

Group	Factor	Variable	Measures
Dependent variables	Product innovation	INNOPROD	1 = firms with product innovation; 0 = otherwise
	Process innovation	INNOPROC	1 = firms with process innovation; 0 = otherwise
Independent variables	Collaboration	CUSTOMERS (DUI mode)	1 = firms that had technological collaboration with customers; 0 = 0 otherwise
		COMPETITORS (DUI mode)	1 = firms that had technological collaboration with competitors; 0 = otherwise
		SUPPLIERS (DUI mode)	1 = firms that had technological collaboration with suppliers; 0 = otherwise
		UNIVERSITIES (STI mode)	1 = firms that had technological collaboration with universities and/or technology centres; 0 = otherwise
	Population size	POPSIZE	1 = firms located in municipalities with <50,000 inhabitants; 0 = otherwise
Control variables	Age	LNAGE	Natural logarithm of the firm age
	Size	LNEMP	Natural logarithm of the number of employees
	Industry	HIGHTECH	1 = firms in high-medium technology sectors; 0 = otherwise
	R&D intensity	RD_SALES	R&D expenditures/Sales (%)

All models were estimated using the *xtlogit* estimator in Stata. In particular, the random-effects estimator, *re*, was used. The estimated residual standard deviation (σ_u), the estimated intraclass correlation (ρ), which is the proportion of the total variance contributed by the panel-level variance component, and the likelihood-ratio test (LR test), which compares the pooled estimator (logit) with the panel estimator (xtlogit), were reported in all estimated models.

4. Empirical results

4.1. Univariate analysis

The descriptive statistics of dependent variables, independent variables, and control variables are shown in Table 1.

The average annual percentage of firms that reported having product and process innovation is 17.33 % and 33.93 %, respectively. By year, the share of firms that reported product innovation declined from 19.11 % in 2009 to 15.54 % in 2016 (Fig. 1). In contrast, the percentage of observed firms which conducted process innovation increased from 32.61 % to 38.44 % in the same period (Fig. 2).

Concerning the DUI and STI innovation modes, Table 2 indicates that, on average, 15.77 % of observed companies collaborated with customers, 2.4 % with competitors, 19.27 % with suppliers, and 23.07 % with universities and/or technology centres. Hence, the type of partner with the highest mean level of interaction is university (STI mode), followed by supply-chain partners (customers and suppliers), and the least present partners are competitors (DUI mode). These partnerships were maintained throughout the analysis period (Fig. 3).

On average, 66.40 % of sample companies are located in municipalities with fewer than 50,000 inhabitants. This percentage has increased over the analysed period from 64.17 % in 2009 to 68.25 % in 2016 (Fig. 4).

Relating the control variables (Table 2), the mean age of the firms is around 33 years, and the average number of workers is near 187. About 35 % of firms operate in high-medium technology industries, while the average ratio of investment in R&D to total sales is 0.80 %.

Finally, Table 3 displays that the variables are not highly correlated.

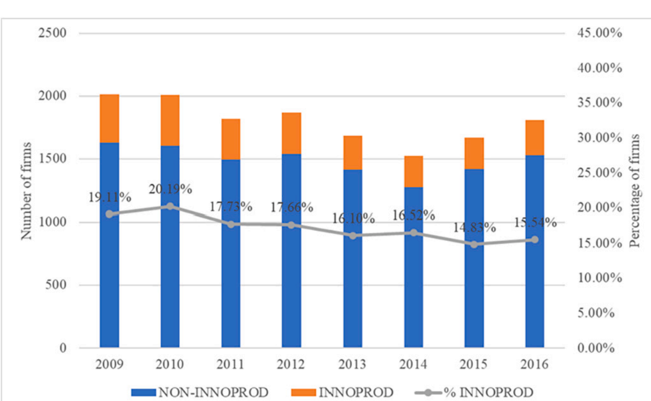

Fig. 1. Product innovation by year.

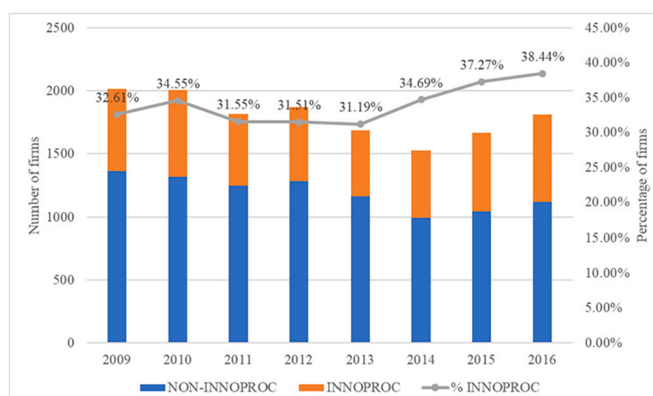

Fig. 2. Process innovation by year.

Table 2
Descriptive statistics of dependent, independent and variables.

Variable	Obs	Mean	Std.Dev.	Min	Max
INNOPROD	14,388	0.1733	0.3785	0	1
INNOPROC	14,388	0.3393	0.4735	0	1
CUSTOMERS	14,388	0.1577	0.3645	0	1
COMPETITORS	14,388	0.0240	0.1532	0	1
SUPPLIERS	14,388	0.1927	0.3944	0	1
UNIVERSITIES	14,388	0.2307	0.4213	0	1
POPSIZE	14,388	0.6640	0.4723	0	1
AGE[a]	13,497	33.1606	19.9270	1	177
EMP[a]	14,388	187.0179	649.2329	1	13,091
HIGHTECH	14,388	0.3482	0.4764	0	1
RD_SALES	14,329	0.8043	2.7603	0	97.46

[a] Variable is not in logs.

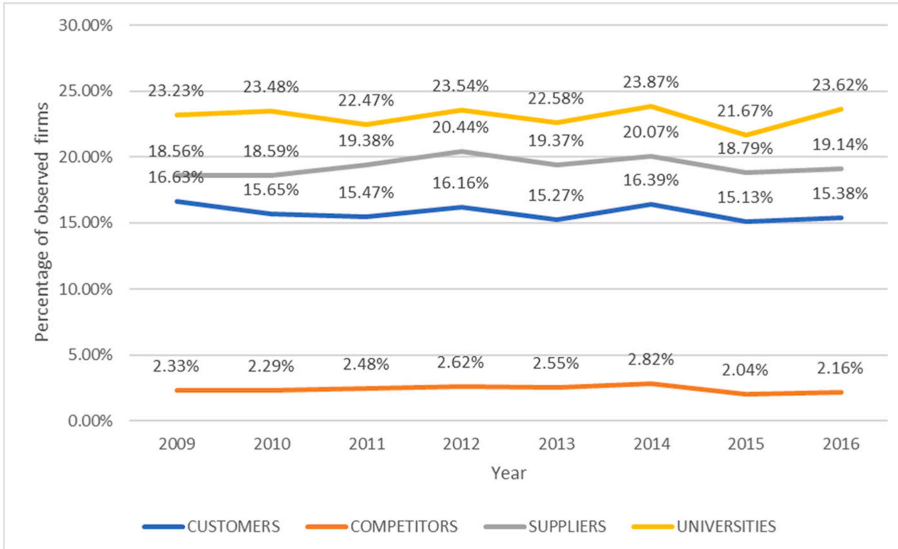

Fig. 3. Collaborating firms with each type of partner by year.

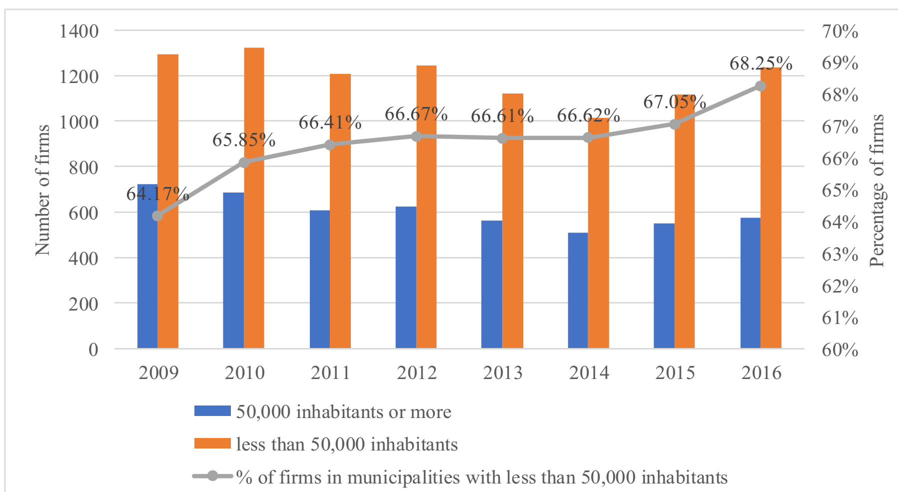

Fig. 4. Number of firms according to the populations size of municipalities by year.

Table 3
Correlation matrix.

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
INNOPROD	(1)	1										
INNOPROC	(2)	0.353*	1									
LNAGE	(3)	0.080*	0.069*	1								
LNEMP	(4)	0.275*	0.332*	0.232*	1							
HIGHTECH	(5)	0.064*	0.050*	−0.001	0.097*	1						
RD_SALES	(6)	0.269*	0.165*	0.032*	0.164*	0.155*	1					
POPSIZE	(7)	−0.035*	−0.001	−0.110*	−0.055*	−0.096*	−0.0484	1				
CUSTOMERS	(8)	0.331*	0.272*	0.117*	0.353*	0.148*	0.297*	−0.034*	1			
COMPETITORS	(9)	0.122*	0.117*	0.045*	0.207*	0.057*	0.187*	−0.039*	0.275*	1		
SUPPLIERS	(10)	0.390*	0.340*	0.150*	0.428*	0.096*	0.299*	−0.042*	0.668*	0.270*	1	
UNIVERSITIES	(11)	0.324*	0.304*	0.141*	0.451*	0.109*	0.286*	−0.032*	0.437*	0.216*	0.486*	1

Notes: The Pearson correlation coefficients for the variables considered in the empirical analysis are showed. *, **, *** denote significance at the 5 %, 1 %, and 0.1 % levels.

4.2. The effect of DUI and STI partnerships and the population size on firm innovation

Table 4 shows the results of the random-effects panel data *logit* regressions. As mentioned, in the first step, the direct effect of DUI and STI learning modes and the population size on the probability of (product and process) innovation is explored (Hypotheses 1 and 2).

The estimated coefficients in Table 4 reveal that, in general, STI and DUI learning modes have a positive effect on product and process innovation, confirming Hypotheses 1 (1a and 1b). Only DUI cooperation with competitors fails to be significant when the dependent variable is product innovation. These results are partly aligned with those obtained by Chen et al. (2011), Fitjar and Rodríguez-Pose (2013), González-Pernía et al. (2015), and Parrilli and Alcalde-Heras (2016).

Table 4
Direct effect of DUI and STI learning modes and the population size on product and process innovation.

	Product innovation				Process innovation			
	Model 1.1	Model 1.2	Model 1.3	Model 1.4	Model 1.1	Model 1.2	Model 1.3	Model 1.4
CONS	−6.705***	−7.267***	−6.307***	−6.672***	−4.288***	−4.572***	−4.020***	−4.194***
	(0.473)	(0.485)	(0.464)	(0.477)	(0.337)	(0.342)	(0.332)	(0.338)
LNAGE	0.057	0.088	0.025	0.056	−0.203*	−0.183*	−0.228*	−0.207*
	(0.121)	(0.124)	(0.118)	(0.121)	(0.091)	(0.093)	(0.090)	(0.091)
LNEMP	0.765***	0.899***	0.684***	0.737***	0.845***	0.919***	0.782***	0.806***
	(0.057)	(0.058)	(0.056)	(0.058)	(0.043)	(0.043)	(0.042)	(0.043)
HIGHTECH	0.011	0.133	0.089	0.080	−0.131	−0.069	−0.088	−0.100
	(0.146)	(0.149)	(0.143)	(0.146)	(0.110)	(0.111)	(0.108)	(0.109)
RD_SALES	0.239***	0.286***	0.219***	0.247***	0.101***	0.125***	0.085***	0.099***
	(0.020)	(0.021)	(0.020)	(0.021)	(0.015)	(0.015)	(0.015)	(0.015)
POPSIZE	−0.047	−0.034	−0.038	−0.043	0.058	0.067	0.066	0.055
	(0.144)	(0.147)	(0.141)	(0.144)	(0.108)	(0.110)	(0.106)	(0.108)
CUSTOMERS	1.389***				0.963***			
	(0.115)				(0.100)			
COMPETITORS		0.128				0.675**		
		(0.223)				(0.215)		
SUPPLIERS			1.596***				1.280***	
			(0.110)				(0.093)	
UNIVERSITIES				1.164***				0.972***
				(0.113)				(0.091)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N° observations	13,443	13,443	13,443	13,443	13,443	13,443	13,443	13,443
N° firms	2364	2364	2364	2364	2364	2364	2364	2364
Log likelihood	−4116.60	−4189.92	−4084.57	−4137.53	−6302.67	−6344.399	−6253.258	−6291.701
Wald X^2	662.3***	530.71***	725.43***	623.55***	699.5***	612.36***	791.96***	715.72***
σ_u	2.498	2.619	2.424	2.522	2.030	2.086	1.984	2.032
ρ	0.655	0.676	0.641	0.659	0.556	0.569	0.545	0.556
LR test of $\rho = 0$	2124.1***	2341.23***	1950.4***	2168.59***	2309.21***	2472.49***	2167.78***	2329.75***

Notes: Robust standard errors in brackets; $^{+}$, *, **, *** denote significance at the 10, 5, 1, and 0.1 % levels.

Additionally, the size of estimated coefficients is consistently larger for product innovation compared to those ones for process innovation. Therefore, product innovation benefits more from engaging in STI or DUI modes than process innovation. This finding is also partly consistent with the arguments that link the STI mode with the creation of advanced scientific knowledge resulting in new products or radical innovations (Fitjar and Rodríguez-Pose, 2013; Parrilli and Alcalde-Heras, 2016). Moreover, DUI cooperation with customers or suppliers may lead to the introduction of new or modified products that better fit the needs of the different agents in the supply-chain, which relates to the results of Chen et al. (2011).

Also, the size of estimated coefficients tends to be larger for DUI mode compared those ones for STI mode; in other words, the effects of DUI mode on innovations are more intense than those ones of STI mode. This finding is consistent with González-Pernía et al. (2015), who found a higher influence of DUI mode on process innovation. This finding is also partly consistent with those of Hervas-Oliver et al. (2021), who conclude that firms in catching-up countries are more dependent on the DUI innovation mode.

The estimated models show that being located in municipalities with fewer than 50,000 inhabitants is not-significantly related to the likelihood of introducing new products or processes. In other words, firms located in less populated areas have not more or less chances of innovating than firms located in more populated municipalities (Hypothesis 2). These results are different to those obtained by Karlsson and Olsson (1998), who found that small firms took advantage of less populated territories, while large firms needed densely-populated regions for developing product innovation. However, these findings are aligned with new research that evidences that innovation is more connected to firms' characteristics and firms' focus on innovation than to location, and firms in peripheral regions can also promote collaborative innovation (Rychen and Zimmermann, 2008; Eder, 2019), if they take advantage of the agglomeration effect because they need access to technology, training programs or knowledge coming from specialized suppliers or distributors (Myles Shaver and Flyer, 2000). The political structure of Spain, organized in autonomous communities with regional governments, could partly explain the "not-bad" prospects of firms located in less populated municipalities for innovating, as in the German case studied by Fritsch and Wyrwich (2021). In other words, the high degree of decentralization of the state in autonomous communities and provincial councils means that some of the essential resources for firm innovation are accessible throughout the territory regardless of the number of inhabitants (e.g. internet connections, road infrastructure, etc.).

Regarding control variables, firm age seems to reduce the probability of having process innovation. The results also suggest that larger firms and more intensive innovation spenders are more likely to report higher innovative performance in terms of product and process innovation. These results are similar to those by Lee and Rodríguez-Pose (2013) and Hervas-Oliver et al. (2021), who relate this result to better access to highly-skilled human resources, but are contrary to those of Parrilli and Radicic (2021), who find a lower capacity of larger firms to take advantage of STI or DUI modes. In turn, working in the high-medium technology industry (HIGHTECH) does not result significant in any of the estimated models, in contrast to the findings of Parrilli and Radicic (2021).

4.3. The moderating role of size population on the relationship between DUI and STI partnerships and firm innovation

To explore the moderating role of population size, Models 1 are extended by including the interactions terms of DUI and STI modes variables with the dummy variable referring to being located in municipalities with fewer than 50,000 inhabitants (Hypothesis 3). Table 5 exhibits the estimated results for product innovation and process innovation.

Concerning the DUI modes, overall, the positive effects of technological collaborations with customers and suppliers on product and process innovation hold in the extended models (Models 2). Therefore, the Hypothesis 1a is supported. In contrast, the models show non-

Table 5
Moderating effect of population size on the relationship between DUI and STI modes and product and process innovation.

	Product innovation				Process innovation			
	Model 2.1	Model 2.2	Model 2.3	Model 2.4	Model 2.1	Model 2.2	Model 2.3	Model 2.4
CONS	−6.685***	−7.277***	−6.322***	−6.600***	−4.271***	−4.571***	−4.003***	−4.200***
	(0.474)	(0.486)	(0.467)	(0.478)	(0.337)	(0.342)	(0.333)	(0.338)
LNAGE	0.056	0.086	0.026	0.056	−0.203*	−0.180+	−0.228*	−0.207*
	(0.121)	(0.124)	(0.118)	(0.121)	(0.091)	(0.093)	(0.090)	(0.091)
LNEMP	0.765***	0.899***	0.683***	0.743***	0.846***	0.920***	0.782***	0.806***
	(0.057)	(0.058)	(0.056)	(0.058)	(0.043)	(0.043)	(0.043)	(0.043)
HIGHTECH	0.008	0.127	0.089	0.087	−0.133	−0.065	−0.089	−0.101
	(0.146)	(0.149)	(0.143)	(0.146)	(0.110)	(0.111)	(0.108)	(0.109)
RD_SALES	0.239***	0.286***	0.219***	0.246***	0.101***	0.125***	0.085***	0.099***
	(0.020)	(0.021)	(0.020)	(0.021)	(0.015)	(0.015)	(0.015)	(0.015)
POPSIZE	−0.075	−0.010	−0.019	−0.184	0.029	0.045	0.035	0.069
	(0.153)	(0.148)	(0.156)	(0.162)	(0.113)	(0.110)	(0.113)	(0.118)
CUSTOMERS	1.318***				0.858***			
	(0.179)				(0.161)			
POPSIZExCUSTOMERS	0.116				0.165			
	(0.225)				(0.197)			
COMPETITORS		0.561				0.186		
		(0.351)				(0.327)		
POPSIZExCOMPETITORS		−0.725				0.845+		
		(0.451)				(0.432)		
SUPPLIERS			1.634***				1.189***	
			(0.176)				(0.150)	
POPSIZExSUPPLIERS			−0.060				0.142	
			(0.214)				(0.182)	
UNIVERSITIES				0.876***				1.009***
				(0.190)				(0.155)
POPSIZExUNIVERSITIES				0.422+				−0.054
				(0.224)				(0.182)
Year dummies	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N° observations	13,443	13,443	13,443	13,443	13,443	13,443	13,443	13,443
N° firms	2364	2364	2364	2364	2364	2364	2364	2364
Log likelihood	−4116.47	−4188.61	−4084.53	−4135.77	−6302.32	−6342.48	−6252.95	−6291.66
Wald X^2	662.38***	531.46***	725.22***	625.84***	700.1***	615.48***	791.83***	715.6***
σ_u	2.498	2.624	2.424	2.522	2.030	2.086	1.986	2.032
ρ	0.655	0.677	0.641	0.659	0.556	0.569	0.545	0.556
LR test of $\rho = 0$	2121.97***	2341.59***	1949.3***	2162.85***	2309.9***	2470.09***	2166.29***	2328.53***

Notes: Robust standard errors in brackets; +, *, **, *** denote significance at the 10, 5, 1, and 0.1 % levels.

significant effects for the interaction terms. In other words, DUI cooperation with customers and suppliers in small municipalities (i.e., <50,000 inhabitants) is associated with an innovation performance likelihood that is not-significantly different from that of such DUI modes in large municipalities (50,000 or more inhabitants). Thus, being located in large municipalities does not make a difference for DUI modes in terms of innovative performance. This is somehow similar to that of Fritsch and Wyrwich (2021), who explain this result by relying on the easy access of German firms to STI and DUI modes through a decentralized political and financial structure, similar to the Spanish one.

Turning our attention to STI mode, it is observed that its positive effect holds for product and process innovation (Hypothesis 1b). Additionally, we found that collaborating firms in small municipalities are more likely to record product innovation relative to the reference category (i.e., non-collaborators) than those located in more populated municipalities. In other words, product innovation benefits more from STI partnerships in less populated municipalities. However, this result must be interpreted with some caution as both the estimated coefficient and the significance level are low, suggesting a weak impact. Additionally, this moderating role of population size is not found in process innovation performance. These results are aligned with those of Eder (2019) and Parrilli and Alcalde-Heras (2016), who reinforce the advantage of peripheral regions that host a university for a firm's innovation, whereas the resources provided by the university are those demanded by the local firms. Other studies also connected the STI with the firm's capacity for product innovation, as it is also evidenced in this

Table 6
Summary of findings for direct effects and interaction terms between DUI and STI learning modes and different thresholds of the municipality's population.

				Customers	Competitors	Suppliers	Universities
INNOPROD	Direct effects			(+)	( )	(+)	(+)
	POPSIZE	≤50,000 (original)	( )	( )	( )	( )	(+)
				(+)	( )	(+)	(+)
	POPSIZE	≤10,000	( )	( )	( )	(−)	( )
				(+)	( )	(+)	(+)
	POPSIZE	≤2000	( )	( )	( )	( )	( )
INNOPROC	Direct effects			(+)	( )	(+)	(+)
	POPSIZE	≤50,000 (original)	( )	( )	(+)	( )	( )
				(+)	(+)	(+)	(+)
	POPSIZE	≤10,000	( )	( )	( )	( )	(−)
				(+)	(+)	(+)	(+)
	POPSIZE	≤2000	( )/(+)	( )	( )	( )	( )

Notes: (+/−/) denote a positive/negative/not significant effect on firm innovation.

analysis (Fitjar and Rodríguez-Pose, 2013; Parrilli and Radicic, 2021).

4.4. Robustness analyses

In order to check the robustness of the findings, additional analyses were conducted. More specifically, we re-run the estimates detailed in Table 5 by setting different thresholds for the number of inhabitants of the municipalities. More specifically, we used two additional dummy variables that take the value of 1 if the municipality has fewer than 10,000 or 2000 inhabitants, and 0 otherwise. These were the only thresholds, apart from <500,000 inhabitants, that could be created from the categorisation of the original variable available in the SSBS.

Table 6 summarizes the main findings for the direct effects of DUI and STI modes and the population size on (product and process) innovation (in the shaded rows and columns, respectively), as well as the moderating effect of the different thresholds of the number of inhabitants. The results prove to be robust to changes in population size thresholds. First, the DUI cooperation with customers and suppliers maintains the positive effect on product and process innovation regardless of the population size of the municipality. In addition, the models show that process innovation also benefits from DUI collaboration with competitors in municipalities with fewer than 10,000 or 2000 inhabitants. Perhaps, in small municipalities, it is easier to cooperate with competitors that enable process innovation (improvements or incremental process innovation), without reaching very high levels of commitment that lead to radical innovations. Therefore, the findings clearly support Hypothesis 1a referring to DUI collaborations with customers and suppliers. Also, the STI collaboration with universities has a positive influence on firm innovation in all the estimated models, supporting Hypothesis 1b.

Second, the different population thresholds are not-significantly related to the likelihood of introducing new products, and only in municipalities with fewer than 2000 inhabitants a positive relationship on process innovation was found in two of the four estimated models (when cooperating with customers and universities). Again, Hypothesis 2 cannot be confirmed.

Finally, weak evidence for a moderating role of population size on the effect of DUI and STI modes on firm innovation is found in only 4 of the 14 models estimated (Hypothesis 3). This weak evidence suggests that innovation outcomes may be lower for technological collaborators located in municipalities with fewer than 10,000 inhabitants compared to those in municipalities with 10,000 inhabitants or more. Although this is isolated evidence, these findings point to the need for further studies to evaluate the potential moderating role of the municipality's size population.

5. Conclusions and implications

Urban agglomerations play a key role in enhancing firms' innovation activities. Nevertheless, it has been shown that firms in less populated areas can also be innovative if they count on other endowments or have access to innovation resources. This finding is aligned with previous contributions of Myles Shaver and Flyer (2000), who found that the firms most interested in forming clusters are those with weaker technologies, less human capital, or worse access to suppliers or distributors, because they benefit more from the agglomeration externalities of accessing competitors' technologies, knowledge suppliers, or distribution channels. Indeed, technological collaboration with external agents can help firms located in less populated areas to overcome the limited access to innovation resources (Tödtling and Trippl, 2018). Even so, firms in less populated territories are once again faced with the difficulty of finding DUI and STI partners in a location where these are scarce compared to more populated territories.

The first aim of this paper was to analyse the effect of the DUI and STI partnerships and the population size of the municipality where the firm is located on its (product and process) innovation. Using a sample of 3004 Spanish manufacturing firms over the period 2009 to 2016, the findings confirm that, generally speaking, product and process innovation benefits from STI and DUI innovation modes; only DUI collaboration with competitors is not-significantly related to product innovation. In more detail, the size of estimated coefficients indicates that product innovation benefits more from engaging in STI or DUI modes than process innovation. Additionally, the results reveal that the innovative performance of Spanish manufacturing firms is more dependent on DUI partnerships than on STI partnerships. In contrast, the firm's location in a low populated municipality seems to have no effect on (product or process) innovation regardless of the threshold used to define low-populated municipalities.

The second aim of this study was to explore whether the effects of DUI and STI learning modes on innovative performance are moderated by the population size of the municipality where firms are located. The estimates show that the innovation performance likelihood of technological collaborators with customers and suppliers in municipalities with <50,000 inhabitants is not significantly different from that of technological collaborators in municipalities with 50,000 or more inhabitants. In contrast, the findings reveal that product innovation benefits more from STI partnerships in municipalities with fewer than 50,000 inhabitants. This evidence insists on the importance of the STI innovation mode in less populated areas for obtaining product innovation, which is connected with the idea of Wixe (2018) that firms located in such areas are more dependent on having highly educated employees to be innovative. It is also aligned with the idea that firms located in peripheral areas are more focused on formal collaboration and use it to compensate for the limited access to local knowledge spillovers (Grillitsch and Nilsson, 2015; Eder, 2019).

Nevertheless, the moderating role of population size changes when considering different thresholds for the number of inhabitants. There is weak evidence that the innovative performance of technological collaborators in municipalities with >10,000 inhabitants is better compared to that of their counterparts in municipalities with 10,000 or fewer inhabitants. Although this evidence is weak, it speaks in favour of gaining insight into the potential moderating role of the location's population size.

The results of this study also enable to make several recommendations to public administrations and authorities. Public policies should focus mainly on increasing collaboration between firms and all actors in the area's innovation system, as this is the starting point for innovation. The firms most interested in technological collaborations in less populated areas will be those that need to collaborate for their product and process innovations at lower structural costs; but this will be only possible if there are valuable knowledge providers such as universities, research labs, or other stakeholders able to share technology or procedures. The government should provide support for companies to become technological collaborators with policies such as staff exchange programs, calls for joint product and process development, or the creation of physical spaces for collaboration, among other measures.

STI collaboration with universities has proven to be effective for firm innovation in less populated areas, university-industry partnerships need to be encouraged by reinforcing the "third mission" of universities as knowledge providers and innovation transfer agents. In fact, the Bill for the Promotion of the Start-up Ecosystem, under discussion since December 2021 in the Spanish Parliament, in its Title VII on the role of universities in the start-up ecosystem, insists on the need to promote programs arising from public-private collaboration, particularly in rural environments (art. 18). Although the final text of the law and its subsequent regulatory development is still pending approval, the government's intention to promote the connection between universities and industry is evident, indicating that it is more necessary in less populated areas. Finally, reducing the entry and exit barriers to the mobility of employees, researchers, or investors will let firms take advantage of reducing structural costs derived from their location in less populated areas.

This study has some limitations. Although different thresholds for the number of inhabitants have been used to check the robustness of the results for alternative sizes of the municipalities, there are other alternatives such as population density or proximity to large cities. Indeed, the data available in SSBS only allow us to consider intervals below 2000, 10,000, 50,000, or 500,000 inhabitants. In this regard, future investigation could benefit from including more appropriate measures of population size. Furthermore, it could be interesting to adopt a multi-level perspective and include some municipality variables that allow us to analyse the effect of externalities from the immediate environment on firm innovation outcomes.

CRediT authorship contribution statement

Nuria Calvo: Conceptualization, Methodology, Writing – original draft, Supervision, Writing – review & editing, Formal analysis. **Sara Fernández-López:** Conceptualization, Data curation, Formal analysis, Writing – original draft, Visualization, Supervision, Validation, Writing – review & editing, Project administration. **María Jesús Rodríguez-Gulías:** Methodology, Software, Data curation, Writing – review & editing, Writing – original draft, Formal analysis. **David Rodeiro-Pazos:** Conceptualization, Methodology, Writing – original draft, Supervision, Writing – review & editing, Formal analysis.

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