Drivers of Cooperative Innovation between Business and Science. The Case of Germany.

Published Version:
Ida D'Attoma, S.P. (2021). Drivers of Cooperative Innovation between Business and Science. The Case of Germany. INTERNATIONAL JOURNAL OF BUSINESS INNOVATION AND RESEARCH, 26(2), 163-193 [10.1504/IJBIR.2021.118439].

Availability:
This version is available at: https://hdl.handle.net/11585/782710 since: 2021-10-27

Published:
DOI: http://doi.org/10.1504/IJBIR.2021.118439

Drivers of cooperative innovation between business and science. The case of Germany

Ida D'attoma*, Silvia Pacei and
Giorgio Tassinari

Department of Statistical Sciences,
University of Bologna,
via delle Belle Arti 41, 40126, Bologna, Italy
Email: Ida.dattoma2@unibo.it
Email: silvia.pacei@unibo.it
Email: giorgio.tassinari@unibo.it
*Corresponding author

Abstract: We examine the determinants of innovation cooperation in general, and with science in particular. First, the focus was on innovative firms: the ones that may decide to cooperate in innovation. Second, the cooperation with science was only defined for firms which decide to cooperate. A trivariate model with double sample selection was estimated to address the potential bias due to self-selected subsamples. Innovative firms that cooperate with science had a better in-house capability, were larger, and received more R&D support than innovators that cooperate with other partners. Furthermore, their probability of cooperating with science increased with the level of protection.

Keywords: innovation cooperation; manufacturing; double selectivity; CIS data; university-industry link.

Reference to this paper should be made as follows: D'attoma, I., Pacei, S. and Tassinari, G. (xxxx) 'Drivers of cooperative innovation between business and science. The case of Germany', *Int. J. Business Innovation and Research*, Vol. X, No. Y, pp.xxx-xxx.

Biographical notes: Ida D'Attoma is a Senior Assistant Professor of Economic Statistics at the Department of Statistical Sciences at University of Bologna in Italy. She received her PhD in Statistical Methodology from the University of Bologna. She is involved in scientific societies and committees. Since 2010, she is a member of the American Evaluation Association and since 2016 she is a member of the Italian Statistical Society. Her research mainly focuses on program evaluation methodology and micro data mining with applications in the areas of policy evaluation. Some her recent works investigates how innovation policies, innovation and/or internationalisation strategies affect firm performance.

Silvia Pacei is an Associate Professor of Economic Statistics, University of Bologna, Department of Statistical Sciences. She is involved in editorial boards (e.g., *Journal of Statistics: Advances in Theory and Applications*). Since 1996, she is a member of the Italian Society of Statistics (SIS) and since 2013 a member of the SIS Coordination Group 'statistics for business' and of the SIS Standing Coordination Group 'methods for sample surveys'. Since 2014, she is a member of the Italian Regional Science Association. Her main research interests are innovation and internationalisation effects on firm performance, effect of social transfers on income poverty, and small area estimation of economic indicators.

Giorgio Tassinari is a Full Professor of Business Statistics at the Department of Statistical Sciences, University of Bologna, Italy. Since 1984 he is a member of the Italian Statistical Society. His research mainly focuses on the assessment of advertising effects and on the measurement of inequality in income and wealth distributions. He has been the Head of the Department of Statistical Sciences of the University of Bologna from 2000 to 2006, member of the Board of Italian Statistical Society from 2004 to 2008 and editor of the journal *Statistica* from 2005 to 2016.

1 Introduction

There is a broad consensus as to the interactions between industry and science as promoters of knowledge diffusion (e.g., Robin and Schubert, 2013) and evidence based on several empirical studies suggests a positive effect of knowledge transfers from science to industry (Veugelers and Cassiman, 2005). In the last two decades, governments and policy-makers have implemented several programs to foster the cooperation between enterprises and external sources of knowledge, especially public science institutions such as universities. These initiatives are often based on the expectation that university-industry interactions can increase innovation rates in the economy by making use of synergistic effects due to a mutual exchange of information and ideas (Barge-Gil et al., 2010; Spencer, 2001). Several empirical studies have demonstrated a positive relationship between the use of some external knowledge sources and innovative performance (e.g., Oluwatope et al., 2016). The importance of university-industry-government relations for a successful innovation is highlighted by the Triple Helix concept (Etzkowitz and Leydesdorff, 1995), which emphasises the idea that the cooperation among societal actors within adequate networks is crucial for knowledge diffusion, and thus for economic development (Günther, 2004). It is also acknowledged that "universities are playing a critical role in the development of high-tech products and services, in the generation of new knowledge and the spin-off of a new business venture" (Al Kharusi and Al Kindi, 2018). Innovation cooperation between universities and enterprises is also encouraged by the Lisbon strategy (DG IPOL Dep A, 2010) and the Europe 2020 strategy (European Commission, 2010) for its decisive role in preserving Europe's economic competitiveness and as a way to react to the general economic and structural problems the European Union faced during the early 1990s.

As reported in Cardamone and Pupo (2015, p.1), "cooperation between businesses and universities encourages the transfer and sharing of knowledge, helps create long-term partnerships and opportunities, and drives innovation." In this context, formal cooperation between enterprises and science must be studied in order to inform actors and policymakers.

Our objective is to deepen the study of the determinants of innovation cooperation in general, and with science in particular for the German manufacturing firms. To this purpose we simultaneously model the firm's decision to innovate, to cooperate and to cooperate with science. These three decisions taken by the firm lead to a self-selection issue that is usually ignored in the literature. In this paper, science is defined on the basis of the community innovation survey (CIS) questionnaire, which includes not only universities, but also other higher education institutions and government, public, or private research institutes. In general, contrasting cooperation effects might affect a company's decision to enter into a cooperation agreement with science. On the one hand, enterprises that cooperate with public bodies might benefit from the fact that those bodies are not interested in the commercialisation of new ideas, but rather either in further research opportunities or in the production of new knowledge through 'open science' (Robin and Schubert, 2013). Furthermore, public bodies are not direct competitors on the output markets of the cooperating enterprise, and the inability to obtain exclusive benefits from the new know-how generated is thus not an issue (Veugelers and Cassiman, 2005). On the other hand, differences in objectives and the nature of public bodies' research might represent a barrier to cooperation. Divergence in objectives may mainly concern the time horizon (long-term versus short-term) and knowledge dissemination (public disclosure vs. non-disclosure) (Robin and Schubert, 2013). However, enterprises can consider public research institutes stable and reliable partners, thanks to their inertia against market turbulence and the government funds available for them (Ahrweiler et al., 2011). For those reasons, Hall (2003) described the university-industry relationship as the 'two-worlds' paradox.

It is evident that the literature on business-science cooperation in innovation has exponentially evolved over time, giving rise to a large body of research on this topic. Nevertheless, there are no definitive conclusions on the drivers of cooperation with science and, as already anticipated, little or superficial attention has been devoted to the selection issue that, if not properly considered, may bias results. Our analysis is motivated by a call for more rigorous methods, which take this problem into greater consideration in order to generalise findings (e.g., Vivas and Barge-Gil, 2015). In this scenario, our goal is to provide more in-depth knowledge about strategic determinants that lead enterprises to cooperate in innovation properly dealing with the selectivity issue. As we will show in the results section, differences between results obtained without properly considering selectivity and those obtained by properly considering it, confirm that for our sample the selection process cannot be ignored. For our purposes, we used micro-data provided by Eurostat in their 2012 CIS for 3,286 German manufacturers that contains very detailed information about firm-level innovations and innovation activities. Germany is an interesting case because in it the percentage of innovative enterprises with cooperative agreements with universities is much higher (more than 30% according to the evidence from 2012 CIS data) than in the rest of European countries. Moreover, Germany has a strong science base leveraged by consolidated links between industry and science, with a high public sector expenditure on research (OECD, 2012) and, at the same time, a large share of public research funded by industry. The above considerations have motivated the following research questions:

RQ1 What are the key determinants of a cooperation with science?

By considering the above mentioned 'two-worlds paradox', in order to study the determinants of the cooperation with science, special attention will be devoted to the appropriability issue. Therefore, we put forward the following hypothesis:

H1 The higher the level of protection on the side of firms, the higher the probability to engage in formal cooperation with science.

To answer question RQ1 and verify hypothesis H1, we must consider that those enterprises cooperating with science are a self-selected subgroup of the enterprises which, in general, engage in cooperation because the possibility to cooperate also involves other kinds of partners. To take this fact into account and to verify possible differences with the more specific decision of cooperating with science, we pose the second research question:

RQ2 What are the key determinants for engaging in a formal cooperation with any kind of partner? Are there differences from a cooperation with science?

We model the probability of cooperating with any partner as a function of some determinants of cooperation decision.[1] In this respect, unlike most previous studies that would often consider size, R&D activity, and industrial sector,[2] this paper considers a rich set of cooperation determinants. Furthermore, we must consider that cooperating enterprises are, in turn, a self-selected subgroup of innovative enterprises, because only they might cooperate in R&D. The decision to cooperate in innovation is conditional to the fact of being an innovative firm. Therefore, we modelled the decision to innovate by posing the following research question:

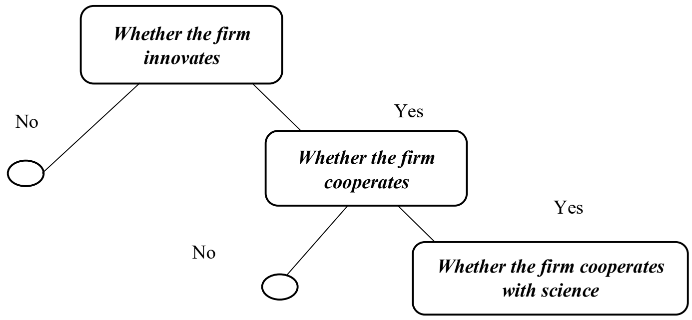
RQ3 What are the drivers of innovation?[3]

The fact of dealing with a sequential decision problem – firms may decide to innovate, and innovative firms may decide to cooperate,[4] while only cooperating firms can cooperate with science – (Figure 1), poses a double selection bias issue especially if the probabilities of innovating, cooperating, and cooperating with science are related two-by-two. Therefore, on the methodological side, unlike the great majority of previous studies that did not consider self-selection, as demonstrated in the recent review by Vivas and Barge-Gil (2015), the potential bias due to selection processes must be addressed.

This paper fills such a methodological gap by targeting the entire population of enterprises and adopting the trivariate probit with double sample selection [Greene, (2012), pp.920–923]. The adopted model takes into account the eventual correlation of residuals across equations, thus leading to efficiency improvements of estimates and making it possible to estimate cross-equation marginal effects. Furthermore, as the second and third outcomes are defined on self-selected subsamples, our model enables us to determine whether the two selection processes introduce bias and, if so, as happens in our empirical analysis, to address that issue.

The paper is organised as follows. Section 2 describes the conceptual framework and reviews the literature on innovation cooperation and cooperation with science with a focus on the appropriability issue; Section 3 presents data and variables; Section 4 describes the econometric model; Section 5 reports results; Section 6 discusses and Section 7 concludes.

Figure 1 The three stages sequential decision problem



2 Conceptual framework and related literature

In this section, we first explore the peculiarities of innovation and cooperation with external partners by manufacturing firms in general. Second, we explore innovation and cooperation with science by devoting special attention to the appropriability issue.

2.1 Innovation and cooperation

In literature, various theories can be found on drivers of innovation cooperation. From the industrial organisation perspective, technological spillovers are the most important factors that affect innovation cooperation (e.g., Kamien et al., 1992). In neoclassical industrial economics, technological spillovers were considered to have a negative effect, as they were expected to reduce the appropriability of the innovation output (i.e., the enterprise's ability to protect and exploit the property rights originating from its innovation) and, consequently, investments in innovation. At the end of the 1980s this view changed, and incentives to engage in R&D appeared far less endangered by technological spillovers. D'Aspremont and Jacquemin (1988) argued that R&D cooperation can lead to higher R&D intensity when the level of technological spillover is significant. Later, Chun and Mun (2012) found that a high level of R&D spillovers in some way increases the probability to engage in a R&D cooperation. Close to this view, there is a strand of empirical innovation literature that predicts that firms engage into cooperative R&D because "this enables them to internalize knowledge spillovers, thus eliminating the disincentive effect of spillovers on R&D" [Scandura, (2016), p.1908].

From the management literature perspective, the resource constraints of enterprises are the most important determinants of R&D cooperation (e.g., Hagedoorn et al., 2000). According to such a perspective, enterprises find partners to access complementary knowledge, either pooling risks or sharing costs (e.g., Hagedoorn, 1993). Cooperation can reduce transaction costs (e.g., Pisano, 1990; Hennart, 1998) and help to maximise enterprise value by combining partners' resources and exploiting their complementarities (Kogout, 1988; Das and Teng, 2000).

According to the transaction costs theory, cooperating enterprises may have more control over technology (Van Beers and Zand, 2014) and, especially small enterprises, may be able to mitigate their innovation disadvantages, stemming from scant technological knowledge and limited access to financial resources (Chun and Mun, 2012).

2.2 Collaboration with science and appropriability

The interest in cooperation with science originates from the recent rise in university-industry partnerships (e.g., Gussoni, 2009) that has spurred a public policy debate on how the industry-science link affects innovative research (e.g., Iskanius and Pohijola, 2016; Segarra-Blasco and Aranzo-Carod, 2008; Cohen et al., 2002).[5]

Several studies have examined the link between enterprises and universities or higher education institutions (Aiello et al., 2019; Gretsch et al., 2019; Hewitt-Dundas et al., 2019; de Moraes Silva et al., 2018; Miozzo et al., 2016; Janeiro et al., 2013; Howells et al., 2012). Howells et al. (2012) explained the university-firm relationship in light of several factors: size, familiarity with universities, absorptive capacity, and ability to share knowledge. Jainero et al. (2013, p.2022) found that "successful enterprises are also those that tend to rely more on universities", and perceived a causal relationship between successful innovation and access to a university as an information source. Gretsch et al. (2019) found that university-industry collaboration has a mixed impact on front-end success depending on the degree of innovativeness, and it particularly strengthens front-end success for more radical innovations.

Aiello et al. (2019) found that export status, firm innovative efforts and the R&D government support are positively related to business-industry links in almost all the countries they examined. Furthermore, among the considered countries, the authors found that meritocratic managerial practices positively affect the university-industry link only in Germany, France and the UK. de Moraes Silva et al. (2018) found size, extramural R&D and product innovativeness as the main industry-science R&D cooperation determinants. Moreover, enterprises cooperating with science are those searching for an up-to-date knowledge (Miotti and Sachwald, 2003) and those belonging to high-tech (HT) sectors, where innovation activities play an important role (Veugelers and Cassiman, 2005).

Drejer and Ostergaard (2017) demonstrated how "the social, cognitive and functional dimensions of employee-driven relations influence university-industry collaboration on innovation" and found that "having employees who are graduates from a specific university in most cases is positively associated with a firm's likelihood to collaborate with that specific university."

Nevertheless, the reasons for cooperating and consequent advantages are still somehow controversial, because of the different objectives of the two partners and the difficulties in evaluating the benefits of cooperation from the standpoint of a single firm (Günther, 2004). A barrier to university-business collaboration is represented by the value and ownership of intellectual property, which further accentuates differences between universities and firm's objectives for innovation (Hewitt-Dundas et al., 2019). In fact, as reported in Hewitt-Dundas et al. (2019), on the side of firms, proprietary knowledge represents a potentially valuable commercial asset, while, on the side of universities, knowledge should be a public good. Furthermore, the authors have found that firms' experience of prior collaboration with non-university partners can generate learning which can help to overcome the 'two-worlds paradox'. This happens, for example, because previous collaborations help to overcome orientation-related and transaction-related barriers to collaboration (Bruneel et al., 2010), or because repeated collaborations allow to establish routines on research targets, dissemination of results and timing of deliverables (Thune, 2011; Gomes et al., 2005; Hall, 2003).

In conceptualising innovation cooperation with science by firms, we assume that firms need to protect themselves before engaging in cooperation with science motivating the hypothesis *H1*. On the one hand, our hypothesis is in line with the stream of literature that assumes that, under strong appropriability regimes, firms are more willing to cooperate in innovation in general (Pisano and Teece, 2007). On the other hand, it is in contrast to the stream of literature that assumes that the incentive for cooperation with science is strong when research outputs cannot be fully appropriated by enterprises (e.g., D'Aspremont and Jacquemin, 1988; Kamien et al., 1992). According to such a view, under imperfect appropriability, cooperation with science may be preferred because universities are not generally interested in the commercialisation of innovation, but rather in new research opportunities.

Obviously, the institutional context affects the nature of innovation as well as the collaborative activities undertaken by the enterprises of a given nation (e.g., Bodas-Freitas and Verspagen, 2017). Love and Roper (2004) found that German enterprises greatly value cost- and risk-sharing and technical rather than market aspects of the innovation process, and they argue that their frequent cooperation is consistent with the strategy of involving potential competitors to reduce the risk of dissipation of property rights. Science and technology innovation policies in Germany are defined within a decentralised, federal political system, where states (Lander) are given a very large degree of autonomy. Regarding innovation cooperation, technology transfer offices form a widespread policy tool common to all Lander and are present in many German universities and public research institutes. These offices play the important role of assisting public research institutes in managing their intellectual assets, and among their tasks there is also that of helping to establish relationships between universities and enterprises. In Germany, knowledge and technology transfer (KTT) have also been a central concern for the federal government since the 1980s. Among other aims, an objective worthy of mention was that of increasing the incentives for universities and other research institutes and, likewise, for enterprises to engage in KTT (Robin and Shubert, 2013).

3 Data sources and variables

This study is based on microdata from the European Union's 'CIS'.[6] National statistical offices conduct the survey following a harmonised questionnaire separately in their country and the dataset are compiled by Eurostat. In particular, we used the CIS 2012 wave for Germany, which refers to the study period 2010–2012. These anonymised data comprise information on 6,328 Germany manufacturing and service enterprises with more than ten employees and, among these, 3,286 manufacturing enterprises represent the focus of our analysis. Of 3,286 German manufacturing enterprises, 75.5% are innovative. Among the innovative enterprises, approximately 49% are engaged in at least one innovation cooperative activity with any type of partner. Among innovative-cooperating enterprises, around 79% are engaged in an innovation cooperation with science. Enterprises cooperating with science may also cooperate with other types of partners: other enterprises within the same enterprise group, suppliers, clients or customers, competitors, consultants and commercial labs.

The rationale for the inclusion of each auxiliary variable in the adopted model is briefly explained below.[7]

3.1 Dependent variables

To answer question RQ1, we constructed a dummy variable that assumes value 1 if the company cooperates with science. Science is a broad concept which includes the cooperation in R&D with universities or higher research institutes and/or government, public or private research institutes and does not permit us to differentiate between the different types. It is worth mentioning that, by construction, the dummy does not rule out the possibility of cooperation with other partners.

To answer question RQ2 we consider a dummy variable that assumes value 1 if the enterprise is engaged in at least one innovation cooperative activity with any type of partner.

Finally, to answer question RQ3 we consider a dummy variable that assumes value 1 if the enterprise has introduced at least one product/process innovation or is engaged in innovation activities not completed or still ongoing.

3.2 Explanatory variables

The firm's size that is generally positively correlated with the probability of cooperating in R&D (e.g., Aristei et al., 2016), is represented by four dummies, whose inclusion in equations enabled us to take into account its possible nonlinear effect on the probability of innovating, innovation cooperation, and innovation cooperation with science. The employee growth rate during the period 2010–2012 was included in order to evaluate the possible link between the growth of the firm and its propensity to cooperate. Exporting behaviour, whose link with innovation is controversial in the literature, is taken into account by an export dummy that is set equal to 1 if enterprises sell goods and/or services in European countries or other countries. Group membership has been considered because it might affect an enterprise's interaction with other enterprises (Aristei et al., 2016). Enterprises which are part of a group are more likely to engage in cooperation to reduce transaction costs and because they are attracted by the higher financial and technological resources available from cooperation partners (Belderbos et al., 2004). We also included a dummy variable that keeps track of whether the firm belongs to a foreign multinational enterprise group. Following Van Beers and Zand (2014), we expect that enterprises with international affiliates would be more likely to engage in formal cooperation with external partners. Furthermore, the educational level of employees was considered because it is linked to the possible drive to resort to cooperation. Also, with the aim of establishing whether enterprises that benefit from some form of public support for R&D are more prone to engage in formal cooperation, we constructed a public financial support dummy[8] that assumes value 1 if the firm receives public incentives from at least one level of government (local or regional, central, European). We expect a positive link between public innovation subsides and cooperation on the basis of several studies that found that enterprises with access to R&D public subsidies tend to cooperate more (e.g., Segarra-Blasco and Aranzo-Carod, 2008). The cost of the innovation process positively affects the use of the knowledge source (e.g., Vivas and Barge-Gil, 2015).

This might be attributed to the fact that expenditures in R&D or other innovation activities could increase enterprises' absorptive capacity (Cohen and Levintal, 1990) and, therefore, in addition to the creation of new knowledge, it might help the firm to exploit knowledge from external sources (e.g., Cardamone and Pupo, 2015). To this end, following Janeiro et al. (2013), we considered the total expenditures on innovation activities in 2012[9] as a measure of innovation intensity, expressed as a percentage of the total turnover, in the same manner as the most common proxy of a firm's absorptive capacity used in the literature. Following Laursen and Salter (2004, 2006) and Robin and Schubert (2013), a count variable for the number of the external sources used, ranging from 0 (no external sources are used) through 10 (all external sources are used), was included as an openness indicator. It is assumed that the more sources a firm uses, the more open and more prone to cooperate it is. Lastly, a dummy variable that considers the importance of building alliances with other enterprises or institutions was considered. It assumes value 1 if the importance is crucial and 0 if it is not. As reasons for using certain knowledge sources, we considered a set of 11 dummies that capture how enterprises rate different types of partners as information sources, which can be interpreted as a type-specific direct measure of the importance of incoming spillovers (see Belderbos et al., 2004). This information was asked in the 2012 CIS survey to innovative firms. We expect that the innovation cooperation with a specific partner is more likely if incoming spillovers from potential partners are crucial. The role played by obstacles to innovation is represented by eight dummies which capture the relevance of several obstacles to meeting enterprise goals and potentially lead the firm to engage in innovation cooperation with other partners.

In addition to the determinants of cooperation abovementioned, as determinants of innovation cooperation with science we also considered the appropriability mechanism, which is acknowledged as an organisational determinant of partner selection (Van Beers and Zand, 2014). This is a key mechanism in protecting the intellectual property and competitive advantage of a firm (Cohen et al., 2000; Geroski, 1995) and is expected to influence the firm's choice of partner (Van Beers and Zand, 2014). Following Aristei et al. (2016), we built a variable that approximates the appropriability condition. We constructed it by summing up a set of eight dummies created for each form of protection adopted by the firm,[10] and then obtained a rescaled measure by dividing the value obtained by 8. Based on such an indicator, as hypothesised in the conceptual framework section, we expect that the higher the forms of protection number, the more willing enterprises are to engage in cooperation with science to the detriment of other types of partners.

As determinants of the innovation decision, we included traditional firm characteristics (i.e., export status, group membership, size). Lastly, the sector of activity was included in all the equations. Considering that the technological intensity of the sector is an important determinant of the heterogeneity of the firm's innovation cooperative behaviour (Gussoni, 2009), we created a new enterprise classification by sectors, which was more appropriate for our purposes, by aggregating the available two-digit NACE classification according to the technology intensity of sectors [see Eurostat indicators of HT industry (OECD, 2003)].

4 Econometric analysis

In our empirical setting, only innovative firms can cooperate in innovation and, only cooperating enterprises can cooperate with science. When decisions are sequential, if there are common omitted variables, decisions will be correlated. For this reason, to estimate the above three-stage decision problem, this study used the trivariate probit with double sample selection [Greene, (2012), pp.920–923] that allows for correlated residuals across equations. We consider the following dependent variables: y_{1i}, that is equal to 1 whether the i^{th} firm innovates and 0 otherwise; y_{2i}, that is equal to 1 whether the i^{th} firm cooperates and 0 otherwise; y_{3i}, that is equal to 1 whether the i^{th} firm cooperates with science and 0 otherwise. The models for y_2 and y_3 are estimated using groups of self-selected enterprises. Due to self-selection we cannot identify $P(y_2 \mid y_1 = 0)$, $P(y_3 \mid y_1 = 0)$ and $P(y_3 \mid y_1 = 1, y_2 = 0)$. To obtain unbiased estimates in the second and third regression, they should not be estimated alone, but the factors affecting the decisions to innovate ($y_1 = 1$) and cooperate ($y_2 = 1$) should also be considered. Following Greene (2012, p.726), we assumed the existence of three latent variables corresponding to the above three dichotomous dependent variables and we derived the following three-equation model:

$$\begin{aligned} y_{1i}^* &= \mathbf{x}_{1i}'\boldsymbol{\beta}_1 + \varepsilon_{1i} \quad y_{1i} = 1 \quad \text{if} \quad y_{1i}^* > 0, \quad y_{1i} = 0 \quad \text{otherwise} \\ y_{2i}^* &= \mathbf{x}_{2i}'\boldsymbol{\beta}_2 + \varepsilon_{2i} \quad y_{2i} = 1 \quad \text{if} \quad y_{2i}^* > 0, \quad y_{2i} = 0 \quad \text{otherwise} \\ y_{3i}^* &= \mathbf{x}_{3i}'\boldsymbol{\beta}_3 + \varepsilon_{3i} \quad y_{3i} = 1 \quad \text{if} \quad y_{3i}^* > 0, \quad y_{3i} = 0 \quad \text{otherwise} \end{aligned} \tag{1}$$

With y_{2i} observed only if $y_{1i} = 1$ and y_{3i} observed only if both y_{1i} and y_{2i} are equal to 1. $\mathbf{x}_{mi}'$ is the vector of explanatory variables for the i^{th} firm in the m^{th} equation ($m = 1, 2, 3$), $\boldsymbol{\beta}_m$ is the vector of regression coefficients in the m^{th} equation. Residuals are assumed to be independently and identically distributed and to have a trivariate normal distribution, $\boldsymbol{\varepsilon}_i \sim N(\mathbf{0}, \boldsymbol{\Omega})$ where $\boldsymbol{\varepsilon}_i = (\varepsilon_{1i}, \varepsilon_{2i}, \varepsilon_{3i})$. The terms on the main diagonal of $\boldsymbol{\Omega}$ are normalised to 1, such that the off-diagonal elements ρ_{mj}, $m, j = 1, 2, 3$, $m \neq j$ are correlations among the residuals. If ρ_{12} and ρ_{13} are significantly different from zero, the unobserved characteristics affecting the choice to innovate also affect the possibility of cooperating and cooperating with science, respectively. Moreover, if ρ_{23} is significantly different from zero, the unobserved characteristics affecting the choice to cooperate also affect the possibility of cooperating with science. In those cases, the estimation of the second/third equation individually can lead to serious sample selection bias. On the basis of the assumption mentioned above, $\boldsymbol{\beta}_1$, $\boldsymbol{\beta}_2$, $\boldsymbol{\beta}_3$ can be estimated jointly. The likelihood function for the model may be constructed by considering the probabilities for the four possible outcomes. The probability of a firm innovating, cooperating, and cooperating with science:

$$\begin{aligned} &P\left(y_{1i}^* > 0\right) \cdot P\left(y_{2i}^* > 0 \middle| y_{1i}^* > 0\right) \cdot P\left(y_{3i}^* > 0 \middle| y_{1i}^* > 0, y_{2i}^* > 0\right) \\ &= \Phi_3\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_1, \mathbf{x}_{2i}'\boldsymbol{\beta}_2, \mathbf{x}_{3i}'\boldsymbol{\beta}_3; \rho_{12}, \rho_{13}, \rho_{23}\right) \end{aligned} \tag{2}$$

The probability of a firm innovating, cooperating, but not cooperating with science:

$$\begin{aligned} &\mathrm{P}\left(y_{1i}^{*}>0\right)\cdot P\left(y_{2i}^{*}>0 \mid y_{1i}^{*}>0\right)\cdot P\left(y_{3i}^{*}\leq 0 \mid y_{1i}^{*}>0,\, y_{2i}^{*}>0\right) \\ &=\Phi_{2}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2};\, \rho_{12}\right)-\Phi_{3}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2},\, \mathbf{x}_{3i}'\boldsymbol{\beta}_{3};\, \rho_{12},\, \rho_{13},\, \rho_{23}\right) \end{aligned} \tag{3}$$

The probability of a firm innovating and not cooperating:

$$P\left(y_{1i}^{*}>0\right)\cdot P\left(y_{2i}^{*}\leq 0 \mid y_{1i}^{*}>0\right)=\Phi\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1}\right)-\Phi_{2}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2};\, \rho_{12}\right) \tag{4}$$

And the probability of a firm not innovating:

$$P\left(y_{1i}^{*}\leq 0\right)=1-\Phi\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1}\right) \tag{5}$$

In previous formula $\Phi_3(.)$ denotes the trivariate standard normal cumulative distribution function, $\Phi_2(.)$ is the bivariate standard normal cumulative distribution function, and $\Phi(.)$ is the standard normal cumulative function. Given the possible outcomes and their correspondent probabilities, the log-likelihood function may be written as:

$$\begin{aligned} &\ln L\left(\boldsymbol{\beta}_{1}, \boldsymbol{\beta}_{2}, \boldsymbol{\beta}_{3};\, \rho_{12}, \rho_{13}, \rho_{23}\right) \\ &=\sum_{i=1}^{n}\left\{\begin{array}{l} y_{1i}y_{2i}y_{3i}\ln\Phi_{3}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2},\, \mathbf{x}_{3i}'\boldsymbol{\beta}_{3};\, \rho_{12},\, \rho_{13},\, \rho_{23}\right) \\ +y_{1i}y_{2i}\left(1-y_{3i}\right)\ln\left[\begin{array}{l}\Phi_{2}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2};\, \rho_{12}\right) \\ -\Phi_{3}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2},\, \mathbf{x}_{3i}'\boldsymbol{\beta}_{3};\, \rho_{12},\, \rho_{13},\, \rho_{23}\right)\end{array}\right] \\ +y_{1i}\left(1-y_{2i}\right)\ln\left[\Phi\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1}\right)-\Phi_{2}\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1},\, \mathbf{x}_{2i}'\boldsymbol{\beta}_{2};\, \rho_{12}\right)\right] \\ +\left(1-y_{1i}\right)\ln\left[1-\Phi\left(\mathbf{x}_{1i}'\boldsymbol{\beta}_{1}\right)\right] \end{array}\right\} \end{aligned} \tag{6}$$

Parameter estimates and correlation terms were obtained using the *cmp* Stata command (Roodman, 2011) that implements a maximum simulated likelihood (MSL) estimation method.[11]

MSL methods provide multivariate normal probabilities by simulating likelihoods and then averaging over these. The *cmp* command implements the Geweke-Hajivassiliou-Keane algorithm for this purpose. For further details on MSL estimation, see Greene (2012, par. 15.6).

5 Empirical results

Table 1 shows that the correlation between the first two equations' residuals (*innovation and cooperation*) and the second and the third equations' residuals (*cooperation and cooperation with science*) are significant at the 5% and 10% level, respectively. On the other hand, the correlation calculated between the first and the third equations' residuals is not significant: only the residuals of equations that are next, in the order, are correlated. The atanhrho values can be interpreted as a primary measure of selection bias. Based on their significance, we can conclude that the selection process cannot be ignored. In particular, a negative correlation, such as in this case, may be interpreted from the following behavioural perspective: unobserved firm characteristics that are conducive to innovation do not lead to cooperation, and vice versa, and unobserved firm characteristics that are conducive to the decision to cooperate in general do not lead to the decision to cooperate with science, and vice versa. With reference to the latter, the negative correlation indicates the lack of complementarity between the two phenomena and may be due either to firm-specific characteristics or to factors that are common only to a sub-sample of enterprises.

Table 1 Results for equations' residual correlations

Coefficient	*Estimate*	*Std. err.*	*Z*	*p-value*	*95% confidence interval*	
$Atanhrho_{12}$	–0.8724	0.3574	–2.44**	0.015	–1.573	–0.172
$Atanhrho_{13}$	0.8450	0.8650	0.98	0.329	-0.850	2.540
$Atanhrho_{23}$	–0.7311	0.4211	–1.74*	0.083	–1.556	–0.094

Notes: ***1% significance, **5% significance and *10% significance.
The subscripts 1, 2 and 3 denote the innovation equation, the cooperation equation and the cooperation with science equation, respectively.
Source: Own elaboration of the CIS 2012

The following Sub-sections 5.1–5.3 report the results obtained from the trivariate probit model with double sample selection. Moreover, with the aim to strengthen the need of considering selectivity to obtain unbiased results, we also report and discuss in Sub-section 5.4 the results obtained by estimating three independent univariate probit models, one for each decision stage: innovating, cooperating and cooperating with science (confirming the same set of independent variables used in each equation of the trivariate probit model with double sample selection).

5.1 The probability of innovating

The following variables were significant at the 1 or 5% level: sector, size, employee growth rate, export behaviour, percentage of employees with a university degree, being part of a group, and being a multinational firm. Table 2 (columns 2 and 3) shows that the probability of innovating differs from the reference category (low-tech sectors) to the greatest extent for the HT sectors (+16%), followed by the medium-HT sectors (+10%). Furthermore, the probability of being innovative increases as size classes increase (the smallest class dummy '1–49 employees' was excluded from the model). As reported in Zemplinerovà and Hromàdkova (2012) large firms as compared to small firms have advantages in financing R&D, have the possibility of diversifying the risks connected to innovation and might benefit of scale economies in R&D. In particular, this probability is 5, 13, and 20% higher, respectively, for enterprises belonging to the '50–249 employees', '250–499 employees', and '500 and more employees' classes. Exporters experience a higher probability of innovating (+13%), as well. Furthermore, if either the employment growth rate or the share of qualified personnel increases by 1%, the probability of innovating increases respectively by 12 and 0.4%. Conversely, the probability of being an innovator is lower for enterprises that are part of a group or part of a multinational group (-6% in both cases).

Table 2 Results for the probability of innovating, the probability of cooperating and the probability of cooperating with science

Covariate	*Innovating*		*Cooperating*		*Cooperating with science*	
	AMEs (SE)	*Z*	*AMEs (SE)*	*Z*	*AMEs (SE)*	*Z*
HT	0.164 (0.02)	6.52***	0.102 (0.05)	2.09**	0.083 (0.09)	0.94
Medium-HT	0.098 (0.02)	4.72***	0.033 (0.04)	0.91	0.073 (0.06)	1.28
Medium-low-tech	0.021 (0.02)	1.16	0.003 (0.03)	0.11	0.039 (0.05)	0.79
50–249 employees	0.048 (0.02)	2.62***	0.058 (0.03)	2.18**	0.071 (0.04)	1.69*
250–499 employees	0.128 (0.03)	4.35***	0.181 (0.05)	3.36***	0.148 (0.07)	1.98**
>500 employees	0.202 (0.02)	9.46***	0.310 (0.05)	5.60***	0.390 (0.07)	5.25***
Emp_growth	0.115 (0.04)	2.82***	–0.010 (0.03)	–0.30	0.098 (0.07)	1.44
Export	0.126 (0.02)	6.40***	0.068 (0.04)	2.00**	0.050 (0.06)	0.79
Group membership	–0.062 (0.03)	–1.99**	0.045 (0.045)	1.12	–0.028 (0.06)	–0.56
Foreign multinational	–0.065 (0.03)	–2.16**	0.025 (0.04)	0.66	–0.008 (0.06)	–0.14
Qualified personnel	0.004 (0.00)	7.06***	0.002 (0.00)	3.26***	0.003 (0.00)	2.42**
Openness			–0.005 (0.00)	–1.16		
Support			0.428 (0.03)	13.62***	0.330 (0.10)	3.41***
Innovation intensity			0.046 (0.08)	0.61		
Sentg_crucial			–0.017 (0.02)	–0.75		
Ssup_crucial			0.013 (0.04)	0.34		
Sclpr_crucial			0.021 (0.02)	0.89		
Sclpu_crucial			–0.067 (0.04)	–1.82*		

Notes: ***1% significance, **5% significance and *10% significance.
AMEs are average marginal effects (AMEs). For factor levels they represent the discrete change from the base level. Standard errors (SE) are reported in brackets. Model estimated using 2653 observations.

Source: Own elaboration of the CIS 2012

Table 2 Results for the probability of innovating, the probability of cooperating and the probability of cooperating with science (continued)

Covariate	*Innovating*		*Cooperating*		*Cooperating with science*	
	AMEs (SE)	*Z*	*AMEs (SE)*	*Z*	*AMEs (SE)*	*Z*
Scom_crucial			–0.037 (0.03)	–1.22		
Sins_crucial			0.016 (0.05)	0.30		
Suni_crucial			0.319 (0.05)	6.51***		
Scon_crucial			–0.005 (0.03)	–0.15		
Sjou_crucial			0.110 (0.05)	2.01**		
Spro_crucial			–0.032 (0.06)	–0.54		
Obspr_crucial			0.050 (0.02)	2.09**	–0.064 (0.05)	–1.20
Obsql_crucial			–0.036 (0.02)	–1.43	–0.026 (0.04)	–0.69
Obslde_crucial			0.024 (0.03)	0.83	0.009 (0.04)	0.23
Obscp_crucial			0.061 (0.05)	1.27	–0.013 (0.06)	–0.23
Obsdmk_crucial			–0.008 (0.03)	–0.23	0.049 (0.06)	0.86
Obsprs_crucial			0.000 (0.03)	0.02	–0.048 (0.05)	–1.02
Obsfin_crucial			0.041 (0.04)	1.04	0.053 (0.06)	0.88
Obsamk_crucial			0.014 (0.03)	0.44		
Obsreg_crucial			–0.012 (0.03)	–0.43		
Building alliance			0.069 (0.04)	1.62		
Appropriabillity					0.132 (0.07)	1.77*

Notes: ***1% significance, **5% significance and *10% significance.
AMEs are average marginal effects (AMEs). For factor levels they represent the discrete change from the base level. Standard errors (SE) are reported in brackets. Model estimated using 2653 observations.

Source: Own elaboration of the CIS 2012

Table 3 Individual probit results for the probability of innovating, cooperating and cooperating with science

Covariate	*Innovating*		*Cooperating*		*Cooperating with Science*	
	AMEs (SE)	*Z*	*AMEs (SE)*	*Z*	*AMEs (SE)*	*Z*
High-tech	0.159 (0.02)	7.05***	**0.171** (0.06)	**2.73*****	0.012 (0.05)	0.22
Medium-high-tech	0.099 (0.02)	4.85***	0.072 (0.05)	1.39	0.035 (0.04)	0.78
Medium-low-tech	0.022 (0.02)	1.17	0.030 (0.05)	0.58	0.037 (0.04)	0.85
50–249 employees	**0.046** (0.02)	**2.49****	0.098 (0.04)	2.26**	**0.044** (0.04)	**1.22**
250–499 employees	0.119 (0.03)	4.41***	0.248 (0.06)	4.04***	**0.060** (0.04)	**1.36**
500 and more employees	0.193 (0.02)	10.08***	0.360 (0.05)	7.16***	0.159 (0.03)	5.09***
Emp_growth	0.107 (0.04)	2.55***	–0.042 (0.05)	–0.83	0.058 (0.06)	0.91
Export	0.126 (0.02)	6.40***	0.121 (0.5)	2.57**	0.006 (0.05)	0.13
Group membership	**–0.061** (0.04)	**–1.82***	0.099 (0.06)	1.56	–0.037 (0.05)	–0.67
Foreign multinational	–0.066 (0.03)	–2.18**	0.053 (0.06)	0.65	–0.007 (0.05)	–0.14
Qualified personnel	0.004 (0.00)	7.02***	0.003 (0.00)	2.92***	**0.001** (0.00)	**1.48**
Openness			–0.012 (0.01)	–1.57		
Support			0.507 (0.03)	16.69***	0.264 (0.05)	5.42***
Innovation intensity			0.072 (0.13)	0.56		
Sentg_crucial			–0.048 (0.04)	–1.29		
Ssup_crucial			0.057 (0.06)	0.97		
Sclpr_crucial			0.044 (0.04)	1.16		
Sclpu_crucial			–0.119 (0.07)	–1.75*		

Notes: ***1% significance, **5% significance and *10% significance. Marginal effects are AMEs. For factor levels they represent the discrete change from the base level. SE are reported in brackets. In bold we denote coefficients whose significance changed with respect to the trivate probit with double sample selection.

Source: Own elaboration of the CIS 2012

Table 3 Individual probit results for the probability of innovating, cooperating and cooperating with science (continued)

Covariate	*Innovating*		*Cooperating*		*Cooperating with Science*	
	AMEs (SE)	*Z*	*AMEs (SE)*	*Z*	*AMEs (SE)*	*Z*
Scom_crucial			–0.060 (0.05)	–1.14		
Sins_crucial			0.105 (0.07)	1.36		
Suni_crucial			0.354 (0.04)	7.72***		
Scon_crucial			–0.001 (0.05)	–0.02		
Sjou_crucial			0.175 (0.07)	2.37**		
Spro_crucial			–0.123 (0.10)	–1.21		
Obspr_crucial			0.089 (0.04)	2.20**	**–0.073** (0.03)	**–2.33****
Obsql_crucial			–0.061 (0.04)	–1.44	–0.008 (0.04)	–0.22
Obslde_crucial			0.033 (0.05)	0.72	0.001 (0.04)	0.04
Obscp_crucial			0.109 (0.07)	1.57	–0.028 (0.06)	–0.48
Obsdmk_crucial			–0.022 (0.06)	–0.38	0.050 (0.04)	1.28
Obsprs_crucial			0.001 (0.05)	0.02	–0.057 (0.05)	–1.20
Obsfin_crucial			0.059 (0.06)	0.96	0.038 (0.04)	0.87
Obsamk_crucial			0.023 (0.05)	0.43		
Obsreg_crucial			–0.029 (0.05)	–0.61		
Building alliance			0.091 (0.06)	1.42		
Appropriability scaled					0.103 (0.05)	1.92*
	n = 2,653, Lr chi2 (111) = 420.07, prob. > χ^2 = 0.0000		n = 1,175, Lr chi2 (111) = 595.00, prob. > χ^2 = 0.0000		n = 620, Lr chi2 (111) = 88.21, prob. > χ^2 = 0.0000	

Notes: ***1% significance, **5% significance and *10% significance. Marginal effects are AMEs. For factor levels they represent the discrete change from the base level. SE are reported in brackets. In bold we denote coefficients whose significance changed with respect to the trivate probit with double sample selection.

Source: Own elaboration of the CIS 2012

5.2 The probability of cooperating

Table 2 (columns 4 and 5) provides estimated marginal effects of the potential determinants of cooperation on the probability of cooperating, which is conditional on being an innovative firm. In line with the literature, we found that the firm's technological level is a determinant of cooperation. The conditional probability of cooperating is higher in HT sectors (+10%) than in low-tech sectors consistently with previous studies (e.g., Miotti and Sachwald, 2003), and this is probably due to the more complex innovation projects that they undertake (e.g., Miotti and Sachwald, 2003; Becker and Dietz, 2004; Sandulli et al., 2012). The size is crucial for the decision to cooperate: the probability of being a cooperating firm significantly increases for enterprises with more than 500 employees (+31%), followed by medium-sized (250–499 employees) (+18%), and medium-small (50–249 employees) (+6%), compared to smaller enterprises. In addition, a significant effect of the export behaviour was found, confirming that firms that sell part of their production abroad are more likely to engage in a formal cooperation in innovation (+7%). Conversely to what was expected, being part of a group does not affect the firm's likelihood to cooperate, which is conditional on the decision to innovate. The degree of personnel education is highly significant (+0.2%) and it is commonly associated with the capacity to capture externalities (de Faria et al., 2010) and the ability of enterprises to share knowledge with partners.

The latter is corroborated by findings of Howells et al. (2012) as far as universities are concerned. Rating clients or customers from the public sector as crucial negatively affects the probability of participating in a cooperation agreement (–7%). It thus emerged from our results that enterprises working for the public sector feel less need to cooperate. On average, enterprises that benefit from public funding for R&D are more prone to cooperate (+43%); such a result is in line with the literature (e.g., Aristei et al., 2016). The hypothesis that incoming spillovers positively affect the probability of cooperation is in part confirmed. Among spillover variables we find that only spillovers from universities and scientific journal and trade/technical publications have a significant positive effect on the decision to cooperate (+32% and 11%, respectively), while spillovers from clients or customers from the public sector have a significantly negative effect. This confirms that market relationships with the public sector discourage cooperation, which is seemingly deemed unnecessary or not useful. All these variables can be interpreted as components of the measure of incoming spillovers, and such a result is in line with Chun and Mun (2012), who found that enterprises are more likely to cooperate in R&D when they rate incoming spillovers as crucial. As far as external sources of information are concerned, universities and research institutes have the most important positive impact on the probability of cooperating. It is worthy of note that information stemming from some private market sources does not have any significant impact on the probability of cooperation. The effect of the internal knowledge-flow variable was negative as expected, but not significant. We did not find a significant relationship between R&D intensity and cooperation, in line with König et al. (1994) and Vonortas (1997). An obstacle variable also showed a significant effect: rating the price competition as a crucial obstacle increases the probability of cooperating (+5%), and such a result is in line with our expectations – motivated by literature (e.g., Vivas and Barge-Gill, 2015) – that costs and risks positively affect the use of external knowledge sources.

5.3 *The probability of cooperating with science*

Table 2 (columns 6 and 7) shows the estimated marginal effects of the potential determinants of cooperation with science on the probability of cooperating with science, which is conditional on being a cooperating firm. The probability of cooperating with science significantly increased with the size as for cooperation in general. The sign of its influence was always positive. However, its influence was highly significant for high values of size (more than 500 employees) (+39%), followed by medium-sized (+15%), and medium-low-sized (+7%), compared to low-sized enterprises. Such a result was in line with other studies (e.g., Veugelers and Cassiman, 2005), and might be due to the small enterprises' lack of critical size for cooperating with science (Belderbos et al., 2004). Furthermore, the percentage of qualified personnel positively affects the decision to cooperate with science (+3%), thus confirming literature results. Therefore, investing in employee training may increase the ability of the firm to assimilate knowledge from external sources (Van Beers and Zand, 2014). On average, enterprises that benefit from public funding for R&D were more prone to collaborate with science (+33%), a result consistent with other studies (e.g., Miotti and Sachwald, 2003). Finally, unlike Veugelers and Cassiman (2005), our results showed that the appropriability issue positively affects the enterprises' decision to cooperate with science confirming our hypothesis H1. In our sample, the firm's probability of cooperating with science increased with the level of protection (+13%). Therefore, enterprises that can better appropriate the results of an innovation process have a higher probability of cooperating with science. Such a result was in line with Hall et al. (2001), who found that intellectual property rights matter even in the link between enterprises and universities.

5.4 *Individual probit results*

From Table 1 we note that the correlation coefficients of the error terms between two couples of equations are significant confirming that the selection process cannot be ignored. The results obtained by estimating three independent univariate probit models are reported in Table 3.

Regarding the probability of innovating, the results suggest that the coefficient of size '50–249 employees', for example, does reduce its significance when selectivity issue is not taken into account moving from 1% to the 5% level. The same occurs with reference to the group membership indicator. The results obtained for the probability of cooperating show that various coefficients change somehow their significance. The coefficient of the 'HT' sector, for example, does increase its significance when selectivity issue is not taken into account moving from 5% to the 1% level. The most evident differences are found for the probability of cooperating with science. Differently from what reported in Table 3, the size indicators '50–249 employees' and '250–499 employees' and the 'qualified personnel' variable do not reach significance when selectivity issue is not taken in the account. On the contrary, the variable 'strong price competition' results significant. Therefore, in the science cooperation decision stage, taking into account the selectivity issue matters, and its consideration, while producing unbiased results, does change results interpretation and thereafter affects policy implications. In fact, differently from results obtained considering selectivity, from Table 3 emerges that the probability of cooperating with science increases with the size of firm only for the highest class size (more than 500 employees) (+16%) compared to lowest-sized class, and the percentage of qualified personnel does not affect the decision to cooperate with science. Moreover, the probability of cooperating with science significantly decreases as the strong price competition is rated crucial (–7%).

Differences between the significance of some auxiliary variables obtained estimating three independent univariate probit models and that obtained by estimating the trivariate model confirm that the double selection process cannot be ignored.

6 Discussion

To summarise our results and compare them with those already presented in the literature, we can distinguish the expected and already consolidated results, from those unexpected or conflicting with what is acknowledged in literature.

Most of the significant determinants that we find for innovation, cooperation and cooperation with science are in line with the literature.[12] The size is a crucial determinant for all the choices: the choice to innovate, to cooperate and to cooperate with science. While in the first two cases this result is obvious and acclaimed in the empirical literature, what is more interesting is that the probability of cooperating with science, conditional on cooperation, is higher for larger firms (see for example Belderbos et al., 2004; Veugelers and Cassiman, 2005; Gussoni, 2009). The possibility of cooperating with scientific institutes is evidently connected to the availability of adequate resources to implement an innovation strategy together. Small and medium-sized enterprises lack the critical size necessary to cooperate (e.g., Belderbos et al., 2004), while larger enterprises are more likely to have the necessary absorptive capacity required to cooperate, and this effect appears more evident in the decision to cooperate with science.

Firms belonging to high technology sectors are more prone to innovate and to cooperate. Also this result is expected and consistent with previous studies (Miotti and Sachwald, 2003; Becker and Dietz, 2004; Sandulli et al., 2012). Nevertheless, the type of sector does not affect the probability that a cooperating firm cooperates with science, that is, firms belonging to high technology sectors do not show a preference to cooperate with science or with other partners. This result is in line with Aiello et al. (2019) who found that, in studying the determinants of firm-university linkages in Europe, the sector does not seem to play a significant role in all the examined countries. On the other hand, this result is in contrast with other studies (Veugelers and Cassiman, 2005) that used a more detailed definition of sector of activity.

The degree of personnel education is strictly linked to all the three studied probabilities. This result is widely confirmed in the literature and explained with the ability to share knowledge between cooperating partners (de Faria et al., 2010; Howells et al., 2012; Drejer and Ostergaard, 2017).

Likewise, firms receiving R&D subsidies are more likely to establish research collaborations in general and in particular with science. This result is in line with the literature (Aristei et al., 2016; Miotti and Sachwald, 2003) and means that innovation policies constitute a further incentive to co-operate and to choose, among possible partners, universities and public research institutions. This can be for example the case of the EU-sponsored research consortia, to which German firms may participate.

The fact of being an exporting firm affects the probability of innovating and of cooperating, but it is not significant for the choice of cooperating with science. Even this result can be considered in line with the literature (Dachs et al., 2008; Aristei et al., 2016; Calia et al., 2016). Firms active abroad, although willing to increase competitiveness through cooperation in general, they are not particularly interested in cooperation with science, maybe because of the lack of the specific competencies necessary to engage research projects with university or research institutes or because they consider cooperation with science or other partners (such as customers, suppliers or competitors) equally profitable.

The importance of only certain incoming spillovers on encouraging cooperation is confirmed by our results. These results are in line with the industrial organisation literature, according to which technological spillovers influence firms to engage in cooperation, as spillovers arise when new knowledge created by a firm is also beneficial to other firms (Katz, 1986; D'Aspremont and Jacquemin, 1988; Kamien et al., 1992). Moreover, Belderbos et al. (2004) notice that the effects of spillovers on cooperation depend on which kind of partner the spillovers are from.

On the contrary, the results obtained for being part of a group are unexpected and in contrast with those presented in other works, where the fact of belonging to a business group is found to influence how the firm cooperates with other partners (Miotti and Sachwald, 2003; Aristei et al., 2016). In our case this variable has a negative effect on the probability of innovating and it is not significant for the conditional probabilities of cooperating and cooperating with science. However, the negative sign for the probability of innovating is in line with the analysis of Zemplinerovà and Hromàdkova (2012) who argue that the probability of innovation decreases most likely due to the direct transfer of knowledge and technology from the mother firm. Moreover, the potential positive effect of a group membership on the probability of innovating could also be partially captured by the size dummies.

Finally, our result on appropriability is in contrast to Veugelers and Cassiman (2005, p.373) who found that "a firm's capacity to effectively protect the returns from innovation is not a significant factor for cooperation with universities." On the other hand, our result is in line with the stream of literature that considers the better appropriability conditions linked to the reduction of outgoing spillovers (e.g., Aristei et al., 2016; Abramovsky et al., 2009), and to the greater 'control of the outflow of commercially sensitive information' [Chun and Mun, (2012), p.425], which could reassure enterprises and encourage them to cooperate with science. Moreover, our result is in line with the stream of literature (e.g., Milesi et al., 2017) that emphasises two main risks in the cooperation with public sources of knowledge:

a the possibility that public researchers undertake their own entrepreneurial business

b the possibility that public researchers convey useful information to competitors (e.g., Bonaccorsi and Piccaluga, 1994).

The first risk might be more likely in the Germany case, since it is acknowledged that in some instances, fostered by government assistance and promotion, universities become directly involved in establishing companies on their own (Röpke, 1998), thus justifying the positive sign of the appropriability.

7 Conclusions

This study investigates the determinants of science cooperation among German manufacturing enterprises using an econometric method that addresses the double selectivity problem. Our results shed some light on the profile of cooperating enterprises and enterprises cooperating with science. Cooperating enterprises, compared to non-cooperating enterprises, tend to be larger, belong to HT sectors, receive more R&D subsidies, and have more qualified personnel. The following determinants had a significant (and positive) effect on the more specific decision to cooperate with science: size, the presence of qualified personnel, the granting of R&D subsidies, and the level of protection. The present section is organised as follows. Sub-section 7.1 highlights the contributions offered by the paper, Sub-section 7.2 discusses some implications and Sub-section 7.3 discusses some limitations of the work and identifies possible directions for future research.

7.1 Contributions

As far as the sign of the appropriability indicator is concerned, our study offers an additional interesting contribution to the debate on the determinants of industry-university links. In fact, the sign of the appropriability indicator was in contrast with general findings typical of one stream of the empirical literature (e.g., Veugelers and Cassiman, 2005). Our result confirms that appropriability also matters in the link between enterprises and science, as reported in Hall et al. (2001) with reference to universities. In the Germany case, the positive relationship between appropriability and cooperation with science is probably due to the risks, advocated by a stream of literature, that exist in undertaking a collaboration with universities that might commit to the entrepreneurial culture.

Moreover, the present work offers an important contribution on the methodological side. In order to study the drivers of cooperation between science and firms we propose to estimate the probability of entering a cooperation agreement with science as a multi-stage decision. The subsequent decisions to innovate, cooperate and cooperate with science are simultaneously modelled. This enabled us to consider both innovative and cooperating enterprises as self-selected subpopulations and limit hurdles due to selection bias typical of the three-stage decision problem. This issue had not been considered in the majority of the previous studies which explicitly recognised this lack as a methodological limitation. Considering the selectivity issue, allows to produce unbiased results and generalisable findings and also matters for policy implications. As demonstrated in the results section, contrasting findings, and consequent different policy implications, are derived if considering and not considering the selectivity issue.

7.2 Implications

Some policy implications may be derived from our results. We found that, among innovative enterprises, small size and a lack of qualified personnel led to less cooperation, both in general and with science. Obviously, small sized enterprises suffer from a lack of human, financial, and material resources, which prevents them from engaging in cooperation activities. Small enterprises should be incentivised more than larger ones to develop innovation linkages with external partners, and helped in making contact with partners and in dealing with the knowledge they receive from and share with them.

On the management side, the result obtained for the qualified personnel highlights the strong relationship existing between the presence of high educated workforce and the firm's capability of collaborating with science or other partners. This evidence suggests the chance to foster firm's cooperation in innovation by improving their intellectual capital. This could be done by investing in employee training and development, in order to instil in the employees those skills and knowledge needed to enhance strategies for the collaboration with new partners and the use of their resources.

Furthermore, findings on appropriability suggest that governments in fostering the industry-science collaboration should take into consideration the need of protection on the side of enterprises. A possible practical implication, as suggested in Cunningham and Link (2015), could be that national innovation systems have to be harmonised, with standard terms sheet, intellectual property agreement protocols, industrial partnership agreement templates and common methodologies to assess intellectual property value. The aim is to ensure that the interaction between universities and industry is simplified, protects both parties and allows for effective exploitation. On the management side, firms need to develop appropriability strategies that are not limited to formal methods, like patenting, but involve for example time-to-market and unique skills of employees. This holds especially for those firms that are expanding their activities to other countries.

7.3 Limitations and future research directions

Our study is not without limitations. It was based on a sample of enterprises from Germany, whose cross-sectional nature did not enable us to draw valid conclusions regarding any association or possible causality, as the anonymised CIS data does not allow to match enterprises across different waves. Some empirical studies based on non-anonymised CIS data have considered only the same enterprises available on different waves, at a price of a notably reduced sample size and an imbalance in favour of large sized enterprises. Panel data would have enabled us to analyse the cooperation in innovation behaviour over time and to check, for example, whether previous collaboration with a particular partner might have affected the likelihood of the subsequent collaboration decision. Hewitt-Dundas et al. (2019, p.1319), for example, using a panel data for UK companies which cover the period 2004 to 2014 found evidence that "firms' experience of prior collaborations with non-university partners increases the probability of subsequent university collaboration."

Moreover, our empirical analysis is based on a single country only, which precludes identifying the extent to which different institutional contexts affect the results. Despite only few other studies (Pejić Bach et al., 2015; Robin and Schubert, 2013; Van Beers et al., 2008 being some exceptions) on sources of information and cooperation are conducted on more than one country, we recognise the importance of the institutional context on the decision to cooperate in innovation.

Not only our empirical analysis is based on a single country, but also information was not available on the Lander where enterprises are located, whereas it is well known that the regional environment is an important determinant of firms' innovation activity (Disoska and Toshevska-Trpchevska, 2019). In the case of Germany, disparities among enterprises are above all connected to the part of the country where they are located, Eastern or Western (Günther, 2004). This geographic information would be useful for studying and monitoring differences in firms' innovation behaviour over time.

As far as data availability is concerned, we do not have the information on the geographical proximity between industry and university. A large body of literature assumes that firms located near universities are more prone to collaborate with them and benefit from knowledge spillovers (e.g., D'Este et al., 2013). Furthermore, we cannot identify university characteristics (e.g., academic research quality, university size, faculty/discipline composition, department size) that matter as determinants of university-industry collaboration (see Maietta, 2015).

This empirical work paves the way for further research, leveraging from its limitations. Future research agenda would encompass the following. First, it would be needed a focus on the drivers and the barriers that may be encountered when engaging in a formal cooperation with one or another special type of partner (e.g., horizontal or vertical cooperation vs. science). Second, the costs encountered in developing a relationship with external partners seem to be too high for small enterprises. However, little is known about these costs, and future works might analyse this aspect in detail. Finally, a comparison with different countries and different institutional contexts would be needed in order to strengthen the robustness of results and verify their generality by checking whether they remain valid for other firms.

Disclaimer

This paper is based on anonymous data from Eurostat, *Community Innovation Survey, CIS 2012*. The results and the conclusions are given by the authors and represent their opinions and not those of Eurostat, the European Commission or any of the national statistical authorities whose data have been used. The responsibility for all conclusions drawn from the data lies entirely with the authors.

References

Abramovsky, L., Kremp, E., Lòpez, A., Schmidt, T. and Simpson, H. (2009) 'Understanding co-operative innovative activity: evidence from four European countries', *Economics of Innovation and New Technology*, Vol. 18, No. 3, pp.243–265.

Ahrweiler, P., Pyka, A. and Gilbert, N. (2011) 'A new model for university-industry links in knowledge-based economies', *Journal of Product Innovation Management*, Vol. 28, No. 2, pp.218–235.

Aiello, F., Cardamone, P. and Pupo, V. (2019) 'New evidence on the firm-university linkages in Europe. The role of meritocratic management practices', *International Review of Applied Economics*, Vol. 33, No. 6, pp.831–828.

Al Kharusi, S. and Al Kindi, M. (2018) 'The university innovation model in a unique environment', *International Journal of Business Innovation and Research*, Vol. 17, No. 3, pp.293–303.

Aristei, D., Vecchi, M. and Venturini, F. (2016) 'University and inter-firm R&D collaborations: propensity and intensity of cooperation in Europe', *Journal of Technology Transfer*, Vol. 41, No. 4, pp.841–871.

Barge-Gil, A., Santamarìa, L. and Modrego, A. (2010) 'Complementarities between universities and technology institutes: new empirical lessons and perspectives', *European Planning Studies*, Vol. 19, No. 2, pp.195–215.

Becker, W. and Dietz, J. (2004) 'R&D cooperation and innovation activities of firms – evidence for the German manufacturing industry', *Research Policy*, Vol. 33, No. 2, pp.209–223.

Belderbos, R., Caree, M., Diedere, B., Lokshin, B. and Veugelers, R. (2004) 'Heterogeneity in R&D cooperation strategies', *International Journal of Industrial Organization*, Vol. 22, Nos. 8/9, pp.1237–1263.

Bodas-Freitas, I.M.B. and Verspagen, B. (2017) 'The motivations, institutions and organization of university-industry collaborations in the Netherlands', *Journal of Evolutionary Economics*, Vol. 27, No. 3, pp.379–412.

Bonaccorsi, A. and Piccaluga, A. (1994) 'A theoretical framework for the evaluation of university-industry relationships', *R&D Management*, Vol. 24, No. 3, pp.229–247.

Bruneel, J., D'Este, P. and Salter, A. (2010) 'Investigating the factors that diminish the barriers to university-industry collaboration', *Research Policy*, Vol. 39, No. 7, pp.858–868.

Calia, P., D'Attoma, I. and Pacei, S. (2016) 'Do innovation and offshoring make a difference? An empirical exploration of the effects on the performance of European firms', *International Business Research*, Vol. 9, No. 7, pp.98–115.

Cardamone, P. and Pupo, V. (2015) *R&D Cooperation between Firms and Universities. Some Evidence in Five European Countries*, Working Papers 201501, Università della Calabria, Dipartimento di Economia, Statistica e Finanza 'Giovanni Anania' – DESF.

Carvalho, N., Raposo, V., Preto, M.T. and Carvalho, L. (2019) 'Innovative vs. non-innovative manufacturing SMEs: do strategies and goals differ?', *International Journal of Business Innovation and Research*, Vol. 19, No. 2, pp.251–284.

Chun, H. and Mun, S.B. (2012) 'Determinants of R&D cooperation in small and medium-sized enterprises', *Small Business Economics*, Vol. 39, No. 2, pp.419–436.

Cohen, W.M. and Levinthal, D.A. (1990) 'Absorptive capacity: a new perspective of learning and innovation', *Administrative Science Quarterly*, Vol. 35, No. 1, pp.128–152.

Cohen, W.M. Nelson, R.R. and Walsh, J.P. (2000) *Protecting their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not)*, NBER Working Paper Series 7552 [online] http://www.nber.org/papers/w7552.

Cohen, W.M., Nelson, R.R. and Walsh, J.P. (2002) 'Links and impacts: the influence of pubic research on industrial R&D', *Management Science*, Vol. 48, No. 1, pp.1–23.

Cunningham, J. and Link, A. (2015) 'Fostering university-industry R&D collaborations in European Union countries', *International Entrepreneurship and Management Journal*, Vol. 11, No. 4, pp.849–860.

D'Aspremont, C. and Jacquemin, A. (1988) 'Cooperative and noncooperative R&D on duopoly with spillovers', *American Economic Review*, Vol. 78, No. 5, pp.1133–1137.

D'Este, P., Iammarino, S. and Guy, F. (2013) 'Shaping the formation of university-industry research collaborations: what type of proximity does really matter?', *The Journal of Economic Geography*, Vol. 13, No. 4, pp.537–558.

Dachs, G., Ebersberger, B. and Pyka, A. (2008) 'Why do firms cooperate for innovation? A comparison of Austrian and Finnish CIS 3 results', *International Journal of Foresight and Innovation Policy*, Vol. 4, Nos. 3/4, pp.200–229.

Das, T. and Teng, B.S. (2000) 'A resource-based theory of strategic alliances', *Journal of Management*, Vol. 26, No. 1, pp.31–61.

de Faria, P., Lima, F. and Santos, R. (2010) 'Cooperation in innovation activities: the importance of partners', *Research Policy*, Vol. 39, No. 8, pp.1082–1092.

de Moraes Silva, D.R., Furtado, A.T. and Vonortas, N.S. (2018) 'University-industry R&D cooperation in Brazil: a sectorial approach', *Journal of Technology Transfer*, Vol. 43, pp.285–315.

Directorate-General for Internal Policies Policy Department A: Economic and Scientific Policy (DG IPOL Dep A) (2010) *The Lisbon Strategy 2000–2010: an Analysis and Evaluation of the Methods Used and Results Achieved* [online] https://www.europarl.europa.eu/RegData/

etudes/etudes/join/2010/440285/IPOL-EMPL_ET(2010)440285_EN.pdf (accessed 14 October 2019).

Disoska, E.M. and Toshevska-Trpchevska, K. (2019) 'Innovation performance of European SMEs: determined by regional or firm specific factors?', *International Journal of Business Innovation and Research*, Vol. 20, No. 2, pp.253–265.

Drejer, I. and Ostergaard, C.R. (2017) 'Exploring determinants of firms' collaboration with specific universities: employee-driven relations and geographical proximity', *Regional Studies*, Vol. 51, No. 8, pp.1192–1205.

Etzkowitz, H. and Leydesdoff, L. (1995) 'The triple helix: university-industry-government relations: a laboratory for knowledge-based economic development', *EASST Review*, Vol. 14, No. 1, pp.14–19.

European Commission (2010) *EUROPE 2020: a Strategy for Smart, Sustainable and Inclusive Growth* [online] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF (accessed 14 October 2019).

Geroski, P.A. (1995) 'Markets for technology: knowledge, innovation and appropriability', in Stoneman, P. (Ed.): *Handbook of the Economics of Innovation and Technological Change*, pp.90–131, Blackwell Publishers, Oxford.

Gomes, J.F.S., Hurmelinna, P., Amaral, V. and Blomqvist, K. (2005) 'Managing relationships of the republic of science and the kingdom of industry', *Journal of Workplace Learning*, Vol. 17, Nos. 1/2, pp.88–98.

Greene, W.H. (2012) *Econometric Analysis*, Pearson, Boston, MA.

Gretsch, O., Salzmann, E.C. and Kock, A. (2019) 'University-industry collaboration and front-end success: the moderating effects of innovativeness and parallel cross-firm collaboration', *R&D Management*, Vol. 49, No. 5, pp.835–849.

Günther, J. (2004) 'Innovation cooperation: experiences from East and West Germany', *Science and Public Policy*, Vol. 31, No. 2, pp.151–158.

Gussoni, M. (2009) *The Determinants of Inter-Firms R&D Cooperation and Partner Selection. A Literature Overview*, Discussion Papers 2009/86, Dipartimento di Scienze Economiche (DSE), University of Pisa, Pisa, Italy.

Hagedoorn, J. (1993) 'Understanding the rationale of strategic technology partnering: interorganizational modes of cooperation and sectoral differences', *Strategic Management Journal*, Vol. 14, No. 5, pp.371–385.

Hagedoorn, J., Link, A. and Vonortas, N.S. (2000) 'Research partnership', *Research Policy*, Vol. 29, Nos. 4/5, pp.567–586.

Hall, B.H. (2003) 'On copyright and patent protection for software and databases: a tale of two-worlds', in Grandstrand, O. (Eds.): *Economics, Law and Intellectual Property*, pp.259–277, Springer, Boston, MA.

Hall, B.H., Link, A. and Scott, J.T. (2001) 'Barriers inhibiting industry from partnering with universities: evidence from the advanced technology program', *The Journal of Technology Transfer*, Vol. 26, pp.87–98.

Hennart, J.F. (1988) 'A transaction cost theory of equity joint ventures', *Strategic Management Journal*, Vol. 9, No. 4, pp.361–374.

Hewitt-Dundas, N., Gkypali, A. and Roper, S. (2019) 'Does learning from prior collaboration help firms to overcome the 'two-worlds paradox' in university-business collaboration?', *Research Policy*, Vol. 48, pp.1310–1322.

Howells, J., Ramlogan, R. and Cheng, S. (2012) 'Innovation and university collaboration: paradox and complexity within the knowledge economy', *Cambridge Journal of Economics*, Vol. 36, No. 3, pp.703–721.

Iskanius, P. and Pohijola, I. (2016) 'Leveraging communities of practice in university-industry collaboration: a case study on arctic research', *International Journal of Business Innovation and Research*, Vol. 10, Nos. 2–3, pp.283–299.

Janeiro, P., Proenca, I. and Goncalves, V. (2013) 'Open innovation: factor explaining universities as service firm innovation sources', *Journal of Business Research*, Vol. 66, No. 10, pp.2017–2023.

Kamien, M.I., Muller, E. and Zang, I. (1992) 'Research joint ventures and R&D cartels', *The American Economic Review*, Vol. 82, No. 5, pp.1293–1306.

Katz, M. (1986) 'An analysis of cooperative research and development', *The Rand Journal of Economics*, Vol. 17, No. 4, pp.527–543.

Kogout, B. (1988) 'Joint ventures: theoretical and empirical perspectives', *Strategic Management Journal*, Vol. 9, pp.319–332.

König, H., Licht, G. and Staat, M. (1994) 'F&E-Kooperationen und Innovationsaktivitat. R&D cooperation and innovation activity', in Gahlen, B., Hesse, H. and Ramser, H-J. (Eds.): *Europaische Integrationsprobleme aus wirtschaftswissenschaftlicher Sicht*, pp.219–242, Siebeck, Tubingen.

Laursen, K. and Salter, A. (2004) 'Searching high and low: what types of firms use universities as a source of innovation?', *Research Policy*, Vol. 33, No. 8, pp.1201–1215.

Laursen, K. and Salter, A. (2006) 'Open for innovation: the role of openness in explaining innovation performance among U.K. manufacturing firms', *Strategic Management Journal*, Vol. 27, No. 2, pp.131–150.

Love, J.H. and Roper, S. (2004) 'The organisation of innovation: collaboration, cooperation and multifunctional groups in UK and German manufacturing', *Cambridge Journal of Economics*, Vol. 28, No. 3, pp.379–395.

Maietta, O.W. (2015) 'Determinants of university-firm R&D collaboration and its impact on innovation: a perspective from a low-tech industry', *Research Policy*, Vol. 44, No. 7, pp.1341–1359.

Milesi, D., Verre, V. and Petelski, N. (2017) 'Science-industry R&D cooperation effects on firm's appropriation strategy: the case of Argentine biopharma', *European Journal of Innovation Management*, Vol. 20, No. 3, pp.372–391.

Miotti, L. and Sachwald, F. (2003) 'Co-operative R&D: why and with whom? An integrated framework of analysis', *Research Policy*, Vol. 32, No. 8, pp.1481–1499.

Miozzo, M., Desyllas, P., Lee, H-F. and Miles, I. (2016) 'Innovation, collaboration and appropriability by knowledge-intensive business services firms', *Research Policy*, Vol. 45, No. 7, pp.1337–1351.

OECD (2003) *OECD Science, Technology and Industry Scoreboard*, OECD Publishing, Paris.

OECD (2012) *OECD Science, Technology and Industry Outlook 2012*, OECD Publishing, Paris.

Oluwatope, O.B., Adeyeye, A.D., Egbetokun, A.A., Sami, M., Aremu, F.S. and Siyanbola, W.O. (2016) 'Knowledge sources and innovative performance: evidence from Nigerian manufacturing firms', *International Journal of Business Innovation and Research*, Vol. 10, Nos. 2–3, pp.209–224.

Pejić Bach, M., Lojpur, A., Peković, S. and Stanovčić, T. (2015) 'The influence of different information sources on innovative performance: evidence from France, the Netherlands and Croatia', *South East European Journal of Economics and Business*, Vol. 10, No. 2, pp.89–101.

Pisano, G. (1990) 'The R&D boundaries of the firm: an empirical analysis', *Administrative Science Quarterly*, Vol. 35, No. 1, pp.153–176.

Pisano, G. and Teece, D.J. (2007) 'How to capture value from innovation: shaping intellectual property and industry architecture', *California Management Review*, Vol. 50, No. 1, pp.295–1278.

Robin, S. and Schubert, T. (2013) 'Cooperation with public research institutions and success in innovation: evidence from France and Germany', *Research Policy*, Vol. 42, No. 1, pp.149–166.

Roodman, D. (2011) 'Fitting fully observed recursive mixed-process models with cmp', *The Stata Journal*, Vol. 11, No. 2, pp.159–206.

Röpke, J. (1998) *The Entrepreneurial University: Innovation, Academic Knowledge Creation and Regional Development in a Globalized Economy* [online] http://www.msmt.cz/reforma-terciarniho-vzdelavani/bila-kniha/the-entrepreneurial-university-innovation-academic-knowledge-creation-and-regional-development-in-a-globalized-economy (accessed 15 October 2019).

Rybnicek, R. and Königsgruber, R. (2019) 'What makes industry-university collaboration succeed? A systematic review of the literature', *Journal of Business Economics*, Vol. 89, pp.221–250.

Sandulli, F.D., Fernandez-Menendez, J., Rodriguez-Duarte, A. and Lopez-Sanchez, J.I. (2012) 'Testing the Schumpeterian hypotheses on an open innovation framework', *Management Decision*, Vol. 50, No. 2, pp.1222–1232.

Scandura, A. (2016) 'University-industry collaboration and firms' R&D effort', *Research Policy*, Vol. 45, No. 9, pp.1907–1922.

Segarra-Blasco, A. and Aranzo-Carod, J.M. (2008) 'Source of innovation and industry-university interaction: evidence from Spanish firms', *Research Policy*, Vol. 37, No. 8, pp.1283–1295.

Spencer, J. (2001) 'How relevant is university-based scientific research to private high-technology firms? A United States-Japan comparison', *Academy of Management Journal*, Vol. 44, No. 2, pp.432–440.

Thune, T. (2011) 'Success factors in higher education-industry collaboration: a case study of collaboration in the engineering field', *Tertiary Education and Management*, Vol. 17, No. 1, pp.31–50.

Van Beers, C. and Zand, F. (2014) 'R&D cooperation, partner diversity and innovation performance: an empirical analysis', *Journal of Product Innovation Management*, Vol. 31, No. 2, pp.292–312.

Van Beers, C., Berghall, E. and Poot, T. (2008) 'R&D internationalization, R&D collaboration and public Knowledge institutions in small economies: evidence from Finland and the Netherlands', *Research Policy*, Vol. 37, No. 2, pp.294–308.

Veugelers, R. and Cassiman, B. (2005) 'R&D cooperation between firms and universities. Some empirical evidence from Belgian manufacturing', *International Journal of Industrial Organization*, Vol. 23, Nos. 5–6, pp.355–379.

Vivas, C. and Barge-Gil, A. (2015) 'Impact on firms of the use of knowledge external sources: a systematic review of the literature', *Journal of Economic Survey*, Vol. 29, No. 5, pp.943–964.

Vonortas, N.S. (1997) 'Research joint ventures in the U.S', *Research Policy*, Vol. 26, Nos. 4/5, pp.577–595.

Zemplinerovà, A. and Hromàdkova, E. (2012) 'Determinants of firm's innovation', *Prague Economic Papers*, Vol. 4, pp.487–503.

Notes

1 See the Appendix for a comprehensive list of cooperation determinants.

2 See Vivas and Barge-Gil (2015) for a comprehensive review.

3 We adopt the broad definition of an innovative enterprise used in the CIS questionnaire: a firm which introduced at least one product and/or process innovation, or had an innovation activity that did not result in a product or process innovation because the activity was not completed or is still ongoing.

4 As recently found by Carvalho et al. (2019), innovative and non-innovative manufacturing small and medium-sized enterprises reveal different strategies and most of them are more associated to innovative enterprises.

5 See Rybnicek and Königsgruber (2019) for a comprehensive review.

6 The responsibility for all conclusions drawn from the data lies entirely with the authors.

7 The precise definition of variables is presented in the Appendix that is available upon request.

8 We opted for such a dummy because receiving or not receiving one form of public financial support from a certain level of government does not bar a firm from benefiting from possible other financial support.

9 That is, R&D expenditures plus expenditures on other innovation inputs.

10 Patents, utility patents, design registration, copyrights, trademarks, lead time advantages, complexity of good or services, secrecy.

11 MSL methods provide multivariate normal probabilities by simulating likelihoods and then averaging over these. The cmp command implements the Geweke-Hajivassiliou-Keane algorithm for this purpose. For further details on MSL estimation, see Greene (2012, par. 15.6).

12 In general, the determinants of industry-science cooperation identified in literature are size, age, intra and extramural R&D, ownership structure and innovation subsides (see Maietta, 2015) and, conditional to data availability, are confirmed by our analysis.

Appendix

Table 1 Definition of variables

Label	*Definition*	*Description*	*Type*	*Innovation*	*Cooperation*	*Cooperation with science*
Dependent variables						
PDPS_ATIN	Innovation	=1 if the enterprise has introduced at least one product/process innovation or is engaged in innovation activities not completed or still on-going; =0 otherwise	Dummy	X		
CO	Cooperation	=1 if the enterprise engaged in at least one innovation cooperative activity with any type of partner; =0 otherwise	Dummy		X	
CO_SCIENCE	Science cooperation	=1 if the enterprise is cooperating in R&D with universities or higher research institutes and/or government, public or private research institutes; =0 otherwise	Dummy			X
Explanatory variables						
EXPORT	Export	=1 if the enterprise sells goods and/or services in other European Union or associated countries or in other countries	Dummy	X	X	X
GP	Group membership	=1 if the enterprise belongs to an enterprise group	Dummy	X	X	X
FM	Foreign multinational	=1 if the enterprise headquarter is located outside the own country; =0 otherwise	Dummy	X	X	X
SUPPORT	R&D subsidy	=1 if the enterprise received public funding to R&D; =0 otherwise	Dummy		X	X
RALLX_RAT	Innovation intensity	Total expenditures on innovation activities in 2012 (% of total turnover)	Continuous		X	X
SIZE_4	Enterprise size	Total number of employees in 2012 in class: 49 employees or less; 50–249 employees; 250–499 employees; 500 and more employees	Categorical	X	X	X
EMP_GROWTH	Growth rate	(Total number of employees in 2012 – total number of employees in 2010) / total number of employees in 2010	Continuous	X	X	X

Notes: [1]Possible external sources are: suppliers of equipment, materials, components, or software; clients or customers from the private sector; clients or customers from the public sector; competitors or other enterprises in the same industry; consultants and commercial labs; universities or other higher education institutions; government, public, or private research institutes; conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations. CIS data only indicate that an external source of knowledge is used, but this does not necessarily imply any formal cooperation. The latter is measured using another set of variables.

Table 1 Definition of variables (continued)

Label	*Definition*	*Description*	*Type*	*Innovation*	*Cooperation*	*Cooperation with science*
Explanatory variables						
SECTOR						
	Low-tech	=1 if the enterprise operates in a low-tech sector; =0 otherwise	Dummy	X	X	X
	Medium-low-tech	=1 if the enterprise operates in a medium-low-tech sector; =0 otherwise	Dummy	X	X	X
	Medium-high-tech	=1 if the enterprise operates in a medium-high-tech sector; =0 otherwise	Dummy	X	X	X
	High-tech	=1 if the enterprise operates in a high-tech sector; =0 otherwise	Dummy	X	X	X
EMPUD_VALC	Percentage of enterprise employees with a university degree	Central value of the class. 0: 0%; 2.5: 1% to 4%; 7: 5% to 9%; 17: 10% to 24%; 37: 25% to 49%; 62: 50% to 74%; 87.5: 75% to 100%	Continuous	X	X	X
OPENNESS	Enterprise's openness indicator	Varies from 0 (no external sources are used) to 10 (if all external sources[1] are used)	Count		X	
Source of information						
SENTG_CRUCIAL	Within the enterprise or enterprise group	=1 if the enterprise rates internal information source of high importance; =0 otherwise	Dummy		X	
SSUO_CRUCIAL	Suppliers of equipment, materials, components, or software	=1 if the enterprise rates the corresponding market source of high importance; =0 otherwise	Dummy		X	
SCLPR_CRUCIAL	Clients or customers from the private sector	=1 if the enterprise rates the corresponding market source of high importance; =0 otherwise	Dummy		X	
SCLPU_CRUCIAL	Clients or customers from the public sector	=1 if the enterprise rates the corresponding market source of high importance; =0 otherwise	Dummy		X	
SCOM_CRUCIAL	Competitors or other enterprises in your industry	=1 if the enterprise rates the corresponding market source of high importance; =0 otherwise	Dummy		X	
SINS_CRUCIAL	Consultants and commercial labs	=1 if the enterprise rates the corresponding market source of high importance; =0 otherwise	Dummy		X	
SUNI_CRUCIAL	Universities or higher education institutions	=1 if the enterprise rates the corresponding institutional source of high importance; =0 otherwise	Dummy		X	
SGMT_CRUCIAL	Government, public or private research institutes	=1 if the enterprise rates the corresponding institutional source of high importance; =0 otherwise	Dummy		X	

Notes: [1]Possible external sources are: suppliers of equipment, materials, components, or software; clients or customers from the private sector; clients or customers from the public sector; competitors or other enterprises in the same industry; consultants and commercial labs; universities or other higher education institutions; government, public, or private research institutes; conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations. CIS data only indicate that an external source of knowledge is used, but this does not necessarily imply any formal cooperation. The latter is measured using another set of variables.

Table 1 Definition of variables (continued)

Label	*Definition*	*Description*	*Type*	*Innovation*	*Cooperation*	*Cooperation with science*
Source of information						
SCON_CRUCIAL	Conferences, trade fairs, exhibitions	=1 if the enterprise rates the corresponding 'other' source of high importance; =0 otherwise	Dummy		X	
SJOU_CRUCIAL	Scientific journals and trade/technical publications	=1 if the enterprise rates the corresponding 'other' source of high importance; =0 otherwise	Dummy		X	
SPRO_CRUCIAL	Professional and industry associations	=1 if the enterprise rates the corresponding 'other' source of high importance; =0 otherwise	Dummy		X	
Obstacles to meeting the goals						
OBSPR_CRUCIAL	Strong price competition	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSQL_CRUCIAL	Strong competition on product quality, reputation or brand	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSCP_CRUCIAL	Lack of demand	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSDMK_CRUCIAL	Dominant market share held by competitors	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSPRS_CRUCIAL	Lack of qualified personnel	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSFIN_CRUCIAL	Lack of adequate finance	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy		X	X
OBSAMK_CRUCIAL	High cost of access to new market	=1 if the enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy			X
OBSREG_CRUCIAL	High cost of meeting government regulations or legal requirements	=1 if enterprise rates the corresponding obstacle of high importance; =0 otherwise	Dummy			X
STALL_CRUCIAL	Importance of building alliance with other enterprises or institutions for reaching enterprise's goal	=1 if enterprise rates building alliance of high importance; =0 otherwise	Dummy		X	
APPROPRIABILITY_SCALED	Level of protection	Min = 0 (no protection); max = 1 (all eight form of protection: patents, utility patents, design registration, copyrights, trademarks, lead time advantages, complexity of good or services, secrecy)	Continuous			X

Notes: [1]Possible external sources are: suppliers of equipment, materials, components, or software; clients or customers from the private sector; clients or customers from the public sector; competitors or other enterprises in the same industry; consultants and commercial labs; universities or other higher education institutions; government, public, or private research institutes; conferences, trade fairs, exhibitions; scientific journals and trade/technical publications; professional and industry associations. CIS data only indicate that an external source of knowledge is used, but this does not necessarily imply any formal cooperation. The latter is measured using another set of variables.