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The dark side of R&D collaborations

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ABSTRACT

Collaboration with firms and public research institutions (PRI) is expected to raise the innovative performance of firms. Collaboration is also likely to increase the cost of innovation because of leakages of strategic information, appropriability and coordination problems. When collaborating with PRI the latter problem is expected to be stronger thus raising the probability of project failure. The aim of this paper is to investigate if and to what extent collaboration in R&D projects raises the probability of failure: i.e. abandoning or delaying innovative projects. It also aims at verifying if and to what extent the collaboration with PRI increases the likelihood of failure. We use data from the fourth Italian Community Innovation Survey (CIS 4) which collected data for the three-year period 2002-2004. The empirical results support the hypothesis that collaboration significantly impacts the probability of abandoning or delaying innovative projects, thus raising the cost of innovation. Collaboration with PRI does not raise the likelihood of failure more than what observed for the collaboration with other partners. Moreover, delaying is influenced by cost factors (such as the lack of financial resources) and knowledge factors (such as the lack of qualified personnel); abandonment is significantly associated with market factors (such as uncertain demand).

Keywords: R&D collaboration; project failure; public research institutions

JEL Classifications: O32; L14

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Introduction

Collaboration in innovative activities is expected to be beneficial in terms of risk and competence sharing and, eventually, for the innovation performance of firms (Veugelers and Cassiman, 2005; Aschhoff and Schmidt, 2008; Numprasertchai and Igel, 2005; Iammarino et al., 2012). Notwithstanding this, empirical evidence shows that only a minority of innovative firms declare that they have collaborated to introduce innovations. This share is even smaller when considering the collaboration with public research institutions (PRI) which are supposed to be one of the main sources of new knowledge and innovative ideas. This means that the advantages of collaborations are at least partially offset by disadvantages.

The collaboration in innovation projects may be beneficial for firms in several ways: reaching economies of scale; spreading the risk of the investment; acquiring specialized knowledge. Above all collaboration may have a positive impact on the innovation performance of firms in terms of the higher probability of introducing an innovation and the higher degree of innovativeness (i.e. radical versus incremental innovation).

Investment in R&D and innovation are by themselves characterized by high risk and appropriability problems. Collaboration is expected to raise the appropriability problems because of the difficulties in writing and enforcing contracts on knowledge (intellectual property) production and exchange and because of the increasing risk of disclosing sensible information about firm's strategy and competitive factors.

The high risk of R&D investment depends not only on the difficulty to forecast the expected returns, but also on the high rate of failure of such projects. Failure may consist in the *abandonment* of projects during its development or in the *delay* of its expected time of accomplishment. Abandonment of a project normally results in the loss of the initial investment given the nature of sunk cost that characterizes R&D expenses. The delay may reduce the profitability of the investment, given the increased time to reach the expected benefits.

The effect of collaboration on the probability of failure is ambiguous. On the one hand collaboration may reduce the probability of failure when it allows to acquire specific competences for the project and to exploit economies of scale. On the other hand, collaboration may raise the probability of failure because of coordination problems with partners.

Collaborations with different subjects (customers, suppliers, PRI, etc.) are motivated by different reasons and follow different paths. This may influence the likelihood of project failure and the type of failure (i.e. abandonment or delay).

The collaboration with PRI may take different forms (D'Este and Patel, 2007) and in general poses less problems in terms of information disclosure and appropriability of results than collaboration with other firms. This is because there are no direct competitive relations between firms and PRI given their different aims and orientation, even if the management of intellectual property has increasingly become a strategic issue for PRI (Geuna and Muscio, 2009). However, coordination problems may be more relevant given the cognitive distance between the partners (Muscio and Pozzali, 2013) and the communication problems between people with different experience and background. For this reason we expect that the collaboration with research institutions, though beneficial for the potential results of the innovative effort, should be associated with a high probability of abandoning of delaying a research project.

This paper has two main aims. The first is to verify if and to what extent collaboration in innovation projects raises the probability of failure, i.e. of delaying or abandoning a project. The second is to ascertain if and to what extent the collaboration with PRI raises the likelihood of failure compared with collaboration with other firms.

The paper is based on data from the Fourth Community Innovation Survey (CIS 4) provided by ISTAT. CIS 4 collected data on Italian firms for the three-year period 2002-2004. Italy is an interesting case given the prevalence of small and medium sized firms and the increased needs for those firms to collaborate when investing in innovation projects. Overall, the empirical results support the main hypothesis that collaboration increases the likelihood of failure. However, they do not support the hypothesis of an increased risk of failure when collaborating with PRI.

The paper is organized as follows. In section 2 we review the relevant literature and elaborate the main research questions. In section 3 we provide information about the data used in the empirical part and the econometric methodology used to address the research questions. In Section 4 we present the results of the empirical analysis. Finally, in the concluding section we discuss the implications of such results and possible extension of the study.

Background literature

Compared with the abundant literature on the effects of collaboration on innovation performance, there are fewer works addressing the relation between collaboration and project failure (Radas and Bozic, 2012; Lhuillery and Pfister, 2009; Lokshin et al., 2011).

Lhuillery and Pfister (2009) examine the likelihood of delaying or abandoning an innovation project due to difficulties in partnership, which they call 'cooperation failure'. Using data from the French Community Innovation Survey (CIS) they find that the collaboration with competitors and PRI raises the probability of delaying or abandoning an innovation project. Cooperation failure increases when the collaboration involves a foreign partner and decreases with previous collaborations, thus suggesting the presence of a learning effect. This 'learning effect' is significant for collaborations with PRI but does not reduce the risk of failure when collaborating with competitors or customers.

Lokshin et al. (2011) associate the probability of 'partnership malfunctioning' to the innovative strategy of firms and the resulting networking behavior. Using data from the CIS survey referring to Dutch firms, they find that firms that have a portfolio of different partners perform best. They also find that firms with a persistent product oriented innovation strategy are more likely to obtain more stable partnership outcome, while firms that are not constant in their technological partnerships are more likely to observe negative effects of collaboration on their innovative performance.

Radas and Bozic (2012) analyze the factors that cause delay or abandonment of innovation projects in small and medium sized firms (SMEs) using data from the Croatian CIS. They find that the low level of resources (such as financial resources) and capabilities (capacity to deploy and coordinate resources) contribute to the failure of innovation projects. New knowledge and capabilities may also be acquired through collaboration. Radas and Bozic (2012) show that collaboration increases the probability to innovate, despite delays and abandonment. However, they do not measure the effect of collaboration on the probability of abandoning or delaying projects.

Cuijpers et al. (2011) explicitly examine the contrasting role of collaboration on the probability of project failure; however, they refer to interdepartmental collaboration within the same firm rather than collaboration with third parties. On the one hand collaboration is expected to raise the likelihood of abandoning or delaying projects as a result of coordination problems; on the other

hand collaboration reduces the probability of failure thanks to the acquisition of superior knowledge and capabilities.

Overall, the conclusion of the literature is that collaboration with third parties (either firms or PRI) is expected to increase the cost of innovation because collaboration raises the likelihood of abandoning of delaying projects. However, firms are willing to collaborate to increase their innovative performance.

Hence our first general hypothesis:

H_1 collaboration in innovative activity is expected to increase the costs of innovation in terms of abandonment or delay of projects.

The likelihood of observing the abandonment or the delay of innovation projects depends, among other things, on the type of partner. At first, the main difference is expected to be between the collaboration with other firms (customers, supplier and competitors) and the collaboration with PRI.

Several authors share the idea that collaboration with PRI is more likely to produce problems and failures because of the different nature and aims that characterize firms and PRI. Pavitt (2005) notices that university-industry relations can be extremely difficult for firms to manage and that "managers often complain that universities operated on extended 'time lines' with little regard for the urgent deadlines of business" (Pavitt, 2005, p. 94). Foray and Lissoni (2010) underline the presence of 'institutional obstacles' that tend to undermine the cooperation between academicians and firms: "… the coexistence of two reward systems typical of each system makes the participants' behavior difficult to anticipate, and tends to undermine the establishment of coherent cultural norms for the promotion of cooperation among team members" (Foray & Lissoni, 2010, p. 283).

Bruneel et al. (2010) examine the obstacles associated with university-industry collaborations and divide them in two categories: those related to differences in the orientations of industry and universities (called, orientation-related barriers) and those related to conflicts over the ownership of intellectual property (called transaction-related barriers). Although these barriers may be mitigated through experience and specific organizational mechanisms they cannot be completely overcome.

The latter argument is suggested by Hemmert et al. (2014), according to whom the 'cultural divide' between academia and industry can be partly overcome by repeated interactions and effective contractual safeguards.

On the basis of this literature we propose the following hypothesis:

H_{2a} collaboration with PRI is expected to increase the likelihood of failure (abandonment or delay) of innovation projects compared to collaboration with other firms

Despite this common hypothesis at present there is little empirical evidence supporting it.
Lhuillery and Pfister (2009) find that collaboration is likely to produce a delay or abandonment of innovative projects and that this effect is greater when PRI or competitors are involved. The authors conclude that partnerships between competitors and between firms and PRI yield specific management difficulties, thus raising the probability of cooperation failures. However, cooperation problems do not seem to be specific of the collaboration with PRI and are more dependent on the type of innovative projects rather than on the partner. Indeed the projects with competitors and PRI usually present a more innovative content.
Lokshin et al. (2011) find that the collaboration with university is not significant when explaining the probability of observing what they call a 'bumpy road' in cooperation, i.e. a mal-functioning in R&D technology partnership, which is more dependent on the innovation strategy of firms, i.e. the type of innovation and the continuity in the innovative effort.
The fact that the likelihood of failure when collaborating with PRI is not higher compared with collaborating with other firms may be explained by the more planned nature of university-firm relations; the latter aspect may partially overcome the higher obstacles in university-firm collaborations.

As a result, we could also argue that:

H_{2b} collaboration with PRI is not expected to raise the likelihood of failure (abandonment or delay) of innovation projects compared to collaboration with other firms

Abandonment and delay of innovation projects are different types of failure that may also depend on several hampering factors, such as the lack of funds and competences, the changes in market

conditions, etc. For this reason, in the empirical analysis we verify the above mentioned hypotheses by considering separately these two problems (abandonment and delay).

We do not expect collaboration problems to impact differently on the likelihood of observing the delay or the abandonment of innovation projects. In fact, the typical problems arising in collaborations – appropriability and coordination problems – may result both in the delay or the abandonment of projects.

On the contrary, the other factors hampering innovation projects (such as the lack of funds and competences, the changing in market conditions, the difficulty/impossibility in finding partners) are expected to differently impact on the delay or abandonment of innovation projects.

The literature has proposed several types of factors that may constitute a barrier to innovation. For example D'Este et al. (2012) distinguishes between 'deterring barriers' that discourage firms from undertaking innovation projects and 'revealed barriers' that may hamper the innovation process of innovative firms. In this paper we consider revealed barriers as we focus on factors which influence the failure of projects in innovative firms.

As mentioned above, these factors may refer to the lack of resources, either financial or human resources, the changing market conditions, the higher cost of innovation. As we consider firms that actually engaged in innovation activity, we hypothesize that factors associated with the lack of resources and cost of innovation are expected to impact mainly on the delay rather than the abandonment of projects. In other words, once innovation projects were started, the emergence of such obstacles is expected to induce a delay in its completion (waiting for a solution) rather than the abandonment of the project. The same argument applies for the difficulty/impossibility to find an innovation partner, which basically can be considered as a constraint on resources.[1]

On the contrary, unexpected changes of market conditions, such as a decrease in demand or an increase in competition intensity, are expected to impact more on the decision to abandon the project rather than delaying it.

As a result, we propose the following hypotheses:

H_{3a} the presence of resource constraints is expected to raise the likelihood of delaying rather than abandoning innovation projects

[1] The difficulty/impossibility to find a partner is different from collaboration problems, since the latter emerge once the partner has been found and the collaboration has begun.

H_{3b} the difficulty in finding collaboration partners is expected to raise the likelihood of delaying rather than abandoning innovation projects

H_{3c} the presence market problems is expected to raise the likelihood abandoning rather than delaying innovation projects

Data and methodology

To test the above hypotheses we use quantitative analysis of data derived from the Fourth Community Innovation Survey (CIS 4) of Italian firms provided by ISTAT. The CIS 2004 collected data and information on product and process innovation of Italian firms for the three-year period 2002-2004. The CIS survey collected information about firms' collaborations in innovative activities. In particular, the questionnaire asked whether the firm co-operates with other firms or institutions. Furthermore, "collaborative" firms were asked about the kind of co-operation partners: firms within the same business groups, suppliers, customers, competitors, consultants, universities, public research institutions. Starting form this information we introduce our binary variable for collaboration and for the collaboration with PRI (Universities and Public research institutions).

CIS survey also collected data on 'failures' of innovative projects. More precisely it asked whether in the period considered there were innovations projects abandoned in the concept stage or abandoned once the project started or delayed (with reference to the initial time schedule). In this paper we focus on the *abandonment* once the project was started and on *serious delay* of projects. These two problems are the most costly and frequent types of project failures. CIS also asked about the main hampering factors of innovation activities which are grouped in four broad categories: cost factors (e.g. lack of internal funds, lack of external finance, innovation costs too high), knowledge factors (e.g. lack of qualified personnel, lack of information on technology, lack of information on markets, difficulty in finding cooperation partner for innovation[2]), market factors (e.g. market dominated by incumbent firms, uncertain demand for innovative products, ...). For each variable firms were asked to indicate the relevance of these factors within a range

[2] We perform a principal component analysis for each category of tampering factors, but keep the variable concerning the "difficulty in finding cooperation partner" apart because the relevance such variable has for our analysis and because, in our opinion, it has a different nature from the other variables concerning knowledge hampering factors. It is also different from collaboration problems that arise once the partner was found and the collaboration is in place.

from “zero” (factor not experienced) to “three” which means a high degree of importance (see Table 1 for details).

Dependent variables

Our dependent variables capture failures (malfunctioning) in innovation projects. They are: *Delayed*, which is a dummy variable which equals 1 if during the period considered there were innovation projects seriously delayed and 0 if not; *Abandoned* which is a dummy variable indicating if during the period there were innovation projects abandoned once the project was begun (1) or not (0).

Independent variables

In order to test our hypotheses our main explicative variables are:

- *Collaboration* - dummy variable for collaboration in innovative activities;
- *Collaboration PRI* - dummy variable for collaboration with PRI (1) vs collaboration with firms/no collaboration (0);

For the other factors explaining project failures we consider the following synthetic variables, *Cost factors*, *Market factors*, *Knowledge factors,* obtained through a principal component analysis of the different factors hampering the innovation process (see Appendix A for details). Also among the hampering factors we also consider the variable *Problems in finding cooperation partners*.

As controls we use several variables to account for firms and sector characteristics:

- *Firm size* is the log of sales at the beginning of the period;
- *Group* is a dummy variable for the belonging to a business group;
- *Internal sources* is a variable indicating the importance of internal source of information in carrying out the innovative activity: this variable takes values from 0 (not used) to 3 (highly important). We use this variable and not a measure of R&D intensity, as usually done in this kind of studies, because of the absence of data on R&D investment in the whole period (CIS provide data on R&D only for the final year, 2004) and because many Italian firms (mostly small and medium sized enterprises) do not perform, at least formally, R&D activities. For these reasons we believe that the variable *Internal sources* can be considered a good proxy both for those firms

investing in R&D and for firms that innovate without investing in R&D. For similar reasons also Bruneel et al. (2010) prefer a different variable to the more conventional R&D intensity.

We control for sector characteristics by using dummy variables referring to six aggregates of industries taken at the 2 digit level of the NACE classification: Manufacturing high-tech, Manufacturing low-tech, Other industries, Knowledge intensive services, Other services, Retail. The aggregation of manufacturing industries is based on the OECD classification while the aggregation of service sectors is based on Eurostat (see Appendix B).

The list of the variables used in the empirical analysis is provided in Table 1.

In order to test our hypotheses we use Probit models. In testing H_{2a} and H_{2b} we restrict our analysis to collaborating firms. In this case selection problems are likely to emerge. Therefore, we use both a Probit model and a Probit model with a selection equation for the probability of firms to engage in collaborative activities.

Collaborating firms show higher values of "innovation failures" both in term of abandonment and delay of innovation projects (see Table 2). We notice that firms collaborating with PRI show, on average, higher values of innovation failures than firms collaborating with subjects different from PRI, although these differences are less significant than in the previous case. Moreover, we notice that also for the other variables (hampering factors, affiliation to business groups, firm size, internal sources) collaborating firms usually show higher values than non-collaborating firms and firms collaborating with PRI show higher values than firms collaborating with other subjects.

Empirical results

With reference to H_1, Table 3 and

Table 4 show that the variable *Collaboration* is strongly significant and robust to various specifications in explaining innovation failures both in terms of *Abandoned* and *Delayed*. We notice that the variable *Internal sources* affects positively the probability of a failure in terms of *Delayed*. This result can be explained by considering that the more the internal sources the firm has developed, the more its innovation intensity, and thus the more the likelihood of innovation delays (Cuijpers et al., 2011). This interpretation is in accordance with the fact that, taking the sector *Retail* as reference, more 'innovative' sectors such as *Manufacturing high-tech* and *Knowledge intensive services* affect positively the likelihood of observing an innovation failure.

Firm size presents a non linear relationship with innovation failure (Cuijpers et al., 2011). A possible interpretation could be that smaller firms are more likely to suffer from innovation failures because of the lack of internal organization and resources. On the contrary, larger firms are more likely to suffer from innovation failures because of their higher innovative intensity, which exposes them to higher innovation risks.

We also notice that among the hampering factors explaining projects' delay the most significant are *Cost* and *Knowledge factors* (H_{3a}), while in explaining the projects' abandonment *Market factors* are more significant (H_{3c}). This result is quite intuitive: the presence of hampering factors in terms of cost or knowledge are more likely to delay the innovation process, while the emergence of market obstacles (e.g. uncertain demand for innovative products) are more likely to increase the likelihood of abandoning the innovation project.

The variable *Problems in finding co* (i.e. the impossibility to find innovation partners) positively affects the probability of delaying innovations, while it is not significant in explaining the probability of abandonment (H_{3b}). Furthermore, we highlight that after the inclusion of the variable *Problems in finding co* the variable *Collaboration* remains significant, thus confirming (as noticed above) that they refer to different aspects.

Even when controlling for all the hampering factors, there is still a 'difference' between collaborating and non collaborating firms.

With reference to H_{2a} and H_{2b}, the empirical evidence supports the latter and not the former (see Table 5 and Table 6). Indeed, the variable *PRI_co* is not significant in influencing the probability of project failure. With reference to *Delayed*, we notice that the industry dummies are not significant except *Other services* that shows a negative sign (which means that firms belonging to this sector are less likely to be prone to innovation failures compared to firms belonging to *Retail*). Furthermore, also in this case among the hampering factors the more significant are *Cost factors*, *Knowledge factors* and *Problem in finding co*. However, there are differences when considering the delay of the abandonment of projects: the hypothesis that problems in finding partners (H_{3b}) would influence the likelihood of delaying rather than abandoning a project is only partially confirmed, since this variable affects both types of failures.

With reference to the variable *Abandoned*, we notice that the industry dummies *Manufacturing high-tech*, *Manufacturing low-tech*, *Knowledge intensive services*, *Other services* show a positive

and significant coefficient (compared with *Retail*). We notice also that the variable *Market factors* is significant, though at a different level of significance, and so *Problems in finding co*.

Since in H_{2a} and H_{2b} we focus on a subsample of the original sample, i.e. we restrict our attention to collaborating firms, we also carry out a Probit with a selection equation in order to avoid selection bias. Cameron and Trivedi (2005, p. 551) suggest that in order to avoid identification problems it is desirable that at least one regressor in the selection equation is excluded from the outcome equation. We decided to exclude the variable *Group* which is not significant in the outcome equation (see

Table 5 and Table 6) and which is highly significant in the selection equation (Table 7 and Table 8). H_{2b} is confirmed also by using this procedure, since the variable *PRI_co* is not significant in any specification. We also point out that in the first and in the second specification of Table 7 (*Delayed*) the Wald test for independent equations presents respectively a *p*-value of 0.0740 and 0.0963. Therefore the estimated correlation between the error terms (of the selection and of the outcome equations) is significantly different from zero at a significance level of 10%. On the contrary, in specifications 2 and 3, the estimated correlation between the error terms is not significantly different from zero (*p*-values are, respectively, of 0.2348 and 0.2507). With reference to the variable *Abandoned* (Table 8) we notice that in this case there are two specifications (the third and the fourth ones) in which the estimated correlation between the error terms is significantly different from zero at a significance level of 10% (*p*-values are, of 0.0907 and 0.0757).

At the end, as a further robustness check, we also employ matching estimators: the basic idea of 'matching' is that to compare observations which are as possible as similar, but for the treatment (i.e. the collaboration). The aim is to guarantee that the treated observations are comparable with the non-treated ones. We use two different estimators, the Propensity score matching estimator and the Nearest-neighbour matching estimator. The results we find (see Table 9 - Table 12) confirm the previous analysis. The only difference lies in the fact that when considering the Nearest-neighbour matching estimator, the variable *Collaboration* is 'barely' significant (at about 9%) in explaining the abandonment of a project innovation.

Conclusions

The empirical evidence about Italian firms confirm that the collaboration in innovation projects significantly impacts the probability of abandoning or delaying projects, thus raising the costs of innovation. In deciding to collaborate in innovation projects firms must balance the advantages of collaboration with its cost.

The main result of the analysis is that the collaboration with PRI does not increase the likelihood of failure compared to what observed for other partners. This result counterbalance the anecdotal evidence about the difficulties associated with university-firm collaboration. Our evidence suggests that the type of innovation partner is not significant in explaining innovation failures.

Another interesting result is that the abandonment and delay of projects are associated to different hampering factors. The delay is associated with resource constraints, such as the lack of financial resources or the lack of qualified personnel. On the contrary, the abandonment of projects is associated with market factors (such as a more uncertain demand).

Both, the delay or the abandonment of projects are associated with Problems in finding an innovation partner. This problems is more relevant in explaining collaboration failures than the type of innovation partner (PRI or firms).

This study has some limitations that could be overcome in future research. The first is that CIS data do not allow us to make an empirical analysis based on individual innovation projects. The characteristics of the individual projects could be relevant because failure and collaboration may both depend on different attitudes towards innovation: the more the willingness to start more complex and risky projects the more the likelihood of collaborating and experiencing innovation failures.

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Table 1 - List of variables

Variable	Description
Collaboration	Dummy variable indicating whether the firm cooperate (1) or not (0) on innovation projects with other organizations, during the period considered
Collaboration PRI	Dummy variable for the cooperation on innovation projects with Universities or Public research institutes (1) vs cooperation with organizations different from Universities/non cooperation at all (0).
Collaboration Firm	Dummy variable for the cooperation with private firms (1) vs cooperation with PRI/ non cooperation at all.
PRI_co	Dummy variable for collaboration with PRI (1) vs collaboration with subject different form PRI (0)
Delayed	Dummy variable indicating whether in the period considered there were innovation projects seriously delayed (1) or not (0)
Abandoned	Dummy variable indicating whether in the period considered there were innovation projects abandoned once the project was begun (1) or not (0)
Cost factors	Continuous variable concerning the importance of hampering factors to innovation projects in terms of: lack of funds within the enterprise, lack of financing for external sources, innovation costs too high. This variable is obtained through a principal component analysis. See Appendix
Knowledge factors	Continuous variable concerning the importance of hampering factors to innovation projects in terms of: lack of qualified personnel, lack of information on technology and markets. This variable is obtained through a principal component analysis. See Appendix.
Market factors	Continuous variable concerning the importance of hampering factors to innovation projects due to: market dominated by established enterprises, uncertain demand for innovative goods or services. This variable is obtained through a principal component analysis. See Appendix.
Problems in finding co	Ordered variable for the difficulty in finding cooperation partners for innovation (0-3).
Group	Dummy variable for the belonging to a business group.
Firm size	Logarithm of the sales of the firm in 2002.
Square of firm size	$(\text{Firm size})^2$
Internal sources	Ordinal variable for the importance of internal source of knowledge in innovation activities (0-3).
Sectoral dummies	Manufacturing high-tech, Manufacturing low-tech, Other industries, Knowledge intensive services, Other services, Retail

Table 2 - Descriptive statistics

Variable	Non collaborating firms (1)		Collaborating firms (2)		Firms collaborating with PRI (3)		Mean difference[a]	
N. of observations	5,239		1,116		487			
	Mean	**Std. Dev.**	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**(2)-(1)**	[b]
Abandoned	.0758	.2647	.1219	.3272	.1416	.3491	***	*
Delayed	.4499	.4975	.5815	.4935	.6181	.4863	***	**
Problems in finding co	.8761	1.0177	1.1846	1.0164	1.3080	.9748	***	***
Lack of internal funds	1.3077	1.0946	1.3719	1.0667	1.4825	1.0439	*	***
Lack of external finance	1.1783	1.1221	1.3333	1.1537	1.5749	1.1285	***	***
Cost of innovation too high	1.5684	1.0952	1.5995	1.0494	1.7125	.9997	.	***
Lack of qualified personnel	1.1096	.9832	1.1980	.9820	1.1766	.9283	***	.
Lack of information on technology	.9357	.8885	.9758	.8784	1.0226	.8124	.	.
Lack of information on materials	.8641	.8866	.9713	.8909	1.0698	.8578	***	***
Market dominated by incumbent firms	1.0242	1.0590	1.2034	1.0464	1.3039	1.0174	***	***
Uncertain demand for innovative products	1.0616	1.0224	1.2491	1.0325	1.3614	.9963	***	***
Group	.2959	.4565	.5161.	.5000	.5790	.4942	***	***
Firm size	8.6778	1.7098	9.4755	2.1040	9.9081	2.2050	***	***
Internal sources	1.9112	1.0288	2.1496	.8680	2.2628	.7347	***	***

[a] *** significant at 1% ** significant at 5% * significant at 10%

[b] mean difference between firms collaborating with PRI and firms collaborating with other subjects

Table 3 - Differences among collaborating and non collaborating firms – Delayed (Probit)

	(1) Delayed	(2) Delayed	(3) Delayed	(4) Delayed
Delayed				
Collaboration	0.2827***	0.2738***	0.2172***	0.2068***
	(0.000)	(0.000)	(0.000)	(0.000)
Firm size	-0.0083	-0.2018***	-0.1703**	-0.1710**
	(0.434)	(0.002)	(0.011)	(0.011)
Internal source	0.0908***	0.0921***	0.0834***	0.0837***
	(0.000)	(0.000)	(0.000)	(0.000)
Group	-0.0456	-0.0568	-0.0138	-0.0128
	(0.260)	(0.163)	(0.738)	(0.758)
Manufac. high-tech	0.4387***	0.4415***	0.3200***	0.3181***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. low-tech	0.1033*	0.1054*	0.0116	0.0112
	(0.078)	(0.073)	(0.846)	(0.851)
Other industries	0.0161	0.0099	-0.0627	-0.0663
	(0.804)	(0.879)	(0.343)	(0.316)
Knowl. int. serv.	0.1499**	0.1397**	0.1274**	0.1220*
	(0.018)	(0.027)	(0.047)	(0.057)
Other services	-0.0889	-0.0930	-0.1352*	-0.1395*
	(0.262)	(0.241)	(0.094)	(0.084)
Square of fim size		0.0105***	0.0101***	0.0101***
		(0.003)	(0.005)	(0.005)
Cost factors			0.1510***	0.1469***
			(0.000)	(0.000)
Knowledge factors			0.0933***	0.0789***
			(0.000)	(0.000)
Market factors			0.0384**	0.0297*
			(0.012)	(0.058)
Problem finding co				0.0519***
				(0.009)
Observations	6354	6354	6354	6354
Pseudo R-squared	0.023	0.024	0.067	0.068
Wald Chi-squared	194.1349	203.9603	553.0695	558.4368

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 4 - Differences among collaborating and non collaborating firms - Abandoned (Probit)

	(1) Abandoned	(2) Abandoned	(3) Abandoned	(4) Abandoned
Abandoned				
Collaboration	0.1869***	0.1688***	0.1337**	0.1328**
	(0.001)	(0.003)	(0.022)	(0.023)
Firm size	0.0150	-0.3272***	-0.3241***	-0.3242***
	(0.342)	(0.000)	(0.000)	(0.000)
Internal source	0.0154	0.0181	0.0113	0.0113
	(0.517)	(0.446)	(0.639)	(0.638)
Group	0.0764	0.0560	0.0740	0.0741
	(0.181)	(0.328)	(0.203)	(0.203)
Manufac. high-tech	0.7368***	0.7469***	0.6700***	0.6698***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. low-tech	0.4532***	0.4638***	0.4079***	0.4078***
	(0.000)	(0.000)	(0.000)	(0.000)
Other industries	0.3746***	0.3651***	0.3240***	0.3236***
	(0.002)	(0.002)	(0.007)	(0.007)
Knowl. int. serv.	0.4921***	0.4818***	0.4586***	0.4582***
	(0.000)	(0.000)	(0.000)	(0.000)
Other services	0.6037***	0.6033***	0.5987***	0.5984***
	(0.000)	(0.000)	(0.000)	(0.000)
Square of fim size		0.0183***	0.0185***	0.0185***
		(0.000)	(0.000)	(0.000)
Cost factors			0.0361**	0.0358*
			(0.048)	(0.052)
Knowledge factors			0.0301*	0.0292
			(0.097)	(0.143)
Market factors			0.0857***	0.0851***
			(0.000)	(0.000)
Problem finding co				0.0034
				(0.902)
Observations	6354	6354	6354	6354
Pseudo R-squared	0.026	0.031	0.043	0.043
Wald Chi-squared	87.6850	104.7863	150.0551	150.2367

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 5 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Delayed (Probit)

	(1) Delayed	(2) Delayed	(3) Delayed	(4) Delayed
Delayed				
PRI_co	0.1249	0.1130	0.0329	0.0264
	(0.120)	(0.160)	(0.691)	(0.750)
Firm size	0.0014	-0.4819***	-0.4354***	-0.4423***
	(0.950)	(0.001)	(0.003)	(0.003)
Internal source	0.0878**	0.0805*	0.0777*	0.0750
	(0.047)	(0.070)	(0.089)	(0.101)
Group	-0.1510*	-0.1515*	-0.1054	-0.1016
	(0.099)	(0.100)	(0.257)	(0.275)
Manufac. high-tech	0.2392	0.2622*	0.1489	0.1224
	(0.129)	(0.097)	(0.355)	(0.451)
Manufac. low-tech	-0.0449	-0.0183	-0.0762	-0.0946
	(0.780)	(0.910)	(0.640)	(0.563)
Other industries	0.0673	0.0543	-0.0235	-0.0318
	(0.703)	(0.759)	(0.896)	(0.860)
Knowl. int. serv.	0.2448	0.2156	0.1887	0.1768
	(0.115)	(0.168)	(0.232)	(0.264)
Other services	-0.3273	-0.3219	-0.3890*	-0.4193**
	(0.102)	(0.110)	(0.057)	(0.042)
Square of fim size		0.0244***	0.0229***	0.0232***
		(0.001)	(0.002)	(0.002)
Cost factors			0.1321***	0.1208***
			(0.000)	(0.000)
Knowledge factors			0.1042***	0.0781**
			(0.001)	(0.020)
Market factors			0.0188	0.0064
			(0.620)	(0.868)
Problem finding co				0.1013**
				(0.029)
Observations	1116	1116	1116	1116
Pseudo R-squared	0.020	0.028	0.063	0.067
Wald Chi-squared	30.0797	40.1194	85.0110	90.9730

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 6 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Abandoned (Probit)

	(1) Abandoned	(2) Abandoned	(3) Abandoned	(4) Abandoned
Abandoned				
PRI_co	0.0417	0.0359	-0.0064	-0.0164
	(0.679)	(0.725)	(0.950)	(0.873)
Firm size	0.0432	-0.2194	-0.2237	-0.2431
	(0.123)	(0.208)	(0.216)	(0.192)
Internal source	0.0217	0.0174	0.0234	0.0205
	(0.720)	(0.775)	(0.704)	(0.743)
Group	0.1502	0.1584	0.1816	0.1937
	(0.192)	(0.171)	(0.132)	(0.110)
Manufac. high-tech	1.0049***	1.0150***	0.9628***	0.9273***
	(0.001)	(0.001)	(0.002)	(0.003)
Manufac. low-tech	0.9083***	0.9248***	0.9110***	0.8959***
	(0.004)	(0.004)	(0.004)	(0.004)
Other industries	0.5177	0.5106	0.4780	0.4614
	(0.135)	(0.143)	(0.170)	(0.185)
Knowl. int. serv.	0.8395***	0.8174***	0.8067***	0.7953**
	(0.007)	(0.009)	(0.010)	(0.010)
Other services	0.7976**	0.8005**	0.8244**	0.7913**
	(0.024)	(0.024)	(0.020)	(0.025)
Square of fim size		0.0130	0.0134	0.0143
		(0.125)	(0.128)	(0.115)
Cost factors			0.0483	0.0300
			(0.214)	(0.457)
Knowledge factors			-0.0140	-0.0476
			(0.731)	(0.300)
Market factors			0.1173**	0.0965**
			(0.014)	(0.049)
Problem finding co				0.1460**
				(0.018)
Observations	1116	1116	1116	1116
Pseudo R-squared	0.040	0.043	0.056	0.063
Wald Chi-squared	28.8259	31.2325	41.9038	48.4470

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 7 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Delayed (Probit with a selection equation)

	(1) Delayed	(2) Delayed	(3) Delayed	(4) Delayed
Delayed				
PRI_co	0.1230	0.0992	0.0313	0.0254
	(0.127)	(0.168)	(0.687)	(0.746)
Firm size	-0.0277	-0.5096***	-0.4706***	-0.4768***
	(0.551)	(0.000)	(0.001)	(0.001)
Internal source	0.0788	0.1168***	0.1056**	0.1023**
	(0.202)	(0.004)	(0.023)	(0.029)
Manufac. high-tech	0.1808	0.3940**	0.2544	0.2261
	(0.413)	(0.010)	(0.150)	(0.208)
Manufac. low-tech	-0.0517	-0.0488	-0.0955	-0.1125
	(0.749)	(0.734)	(0.535)	(0.469)
Other industries	0.0445	0.0749	-0.0039	-0.0124
	(0.803)	(0.636)	(0.982)	(0.943)
Knowl. int. serv.	0.1764	0.3716**	0.3042*	0.2896
	(0.464)	(0.020)	(0.087)	(0.106)
Other services	-0.3485*	-0.2003	-0.3092	-0.3413
	(0.093)	(0.320)	(0.148)	(0.115)
Square of fim size		0.0276***	0.0258***	0.0260***
		(0.000)	(0.000)	(0.000)
Cost factors			0.1245***	0.1143***
			(0.000)	(0.000)
Knowledge factors			0.0978***	0.0736**
			(0.002)	(0.024)
Market factors			0.0174	0.0057
			(0.626)	(0.873)
Problem finding co				0.0956**
				(0.033)
Collaboration				
Firm size	-0.2443***	-0.2361***	-0.2362***	-0.2361***
	(0.009)	(0.001)	(0.001)	(0.001)
Square of fim size	0.0167***	0.0163***	0.0163***	0.0163***
	(0.001)	(0.000)	(0.000)	(0.000)
Internal source	0.1053***	0.1046***	0.1048***	0.1048***
	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.2922***	0.2963***	0.2968***	0.2968***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. high-tech	0.3849***	0.3840***	0.3842***	0.3843***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. low-tech	-0.0733	-0.0743	-0.0739	-0.0739
	(0.330)	(0.324)	(0.327)	(0.327)
Other industries	0.0660	0.0651	0.0657	0.0657
	(0.428)	(0.434)	(0.429)	(0.429)
Knowl. int. serv.	0.4268***	0.4253***	0.4260***	0.4260***
	(0.000)	(0.000)	(0.000)	(0.000)
Other services	0.1856*	0.1850*	0.1852*	0.1853*
	(0.056)	(0.057)	(0.057)	(0.057)
Observations	6354	6354	6354	6354
Wald Chi-squared	20.2582	64.1916	105.0917	110.5879

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 8 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Abandoned (Probit with a selection equation)

	(1) Abandoned	(2) Abandoned	(3) Abandoned	(4) Abandoned
Abandoned				
PRI_co	0.0275	0.0287	-0.0081	-0.0162
	(0.743)	(0.747)	(0.925)	(0.851)
Firm size	-0.0126	-0.1063	-0.0976	-0.1100
	(0.734)	(0.525)	(0.560)	(0.516)
Internal source	-0.0404	-0.0331	-0.0321	-0.0362
	(0.471)	(0.584)	(0.595)	(0.546)
Manufac. high-tech	0.6217*	0.7085*	0.6295	0.5902
	(0.072)	(0.076)	(0.103)	(0.116)
Manufac. low-tech	0.7857***	0.8343***	0.8045***	0.7867**
	(0.007)	(0.009)	(0.010)	(0.010)
Other industries	0.3876	0.4171	0.3760	0.3588
	(0.206)	(0.207)	(0.241)	(0.256)
Knowl. int. serv.	0.4471	0.5191	0.4783	0.4599
	(0.188)	(0.175)	(0.200)	(0.207)
Other services	0.5524*	0.6097*	0.6056*	0.5711
	(0.096)	(0.095)	(0.092)	(0.106)
Square of fim size		0.0053	0.0048	0.0054
		(0.564)	(0.596)	(0.557)
Cost factors			0.0409	0.0253
			(0.213)	(0.453)
Knowledge factors			-0.0120	-0.0396
			(0.728)	(0.316)
Market factors			0.0988**	0.0807*
			(0.025)	(0.066)
Problem finding co				0.1212**
				(0.032)
Collaboration				
Firm size	-0.2449***	-0.2359***	-0.2358***	-0.2361***
	(0.001)	(0.001)	(0.001)	(0.001)
Square of fim size	0.0167***	0.0162***	0.0162***	0.0163***
	(0.000)	(0.000)	(0.000)	(0.000)
Internal source	0.1050***	0.1050***	0.1050***	0.1049***
	(0.000)	(0.000)	(0.000)	(0.000)
Group	0.2922***	0.2960***	0.2964***	0.2969***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. high-tech	0.3837***	0.3835***	0.3835***	0.3834***
	(0.000)	(0.000)	(0.000)	(0.000)
Manufac. low-tech	-0.0737	-0.0738	-0.0737	-0.0737
	(0.328)	(0.327)	(0.327)	(0.327)
Other industries	0.0661	0.0666	0.0667	0.0667
	(0.427)	(0.423)	(0.423)	(0.422)
Knowl. int. serv.	0.4277***	0.4278***	0.4279***	0.4278***
	(0.000)	(0.000)	(0.000)	(0.000)
Other services	0.1855*	0.1857*	0.1857*	0.1857*
	(0.056)	(0.056)	(0.056)	(0.056)
Observations	6354	6354	6354	6354
Wald Chi-squared	18.0962	16.3562	29.9205	37.3911

p-values in parentheses
* p<0.10, ** p<0.05, *** p<0.01

Sector Retail is taken as reference

Table 9 - Differences among collaborating and non collaborating firms – Delayed and Abandoned (Propensity score matching. Average treatment effect on the treated)

Dependent variable	Treatment variable	Coefficient	p-values
Delayed	Collaboration	0.1317***	0.000
Abandoned	Collaboration	0.0416***	0.004
Observations	6,354		
Other indep. var.	Firm size, Square firm size, Internal sources, Group, Sector dummies		

*** p<0.10, ** p<0.05, * p<0.10, Treatment model: Probit

Table 10 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Delayed and Abandonment (Propensity score matching. Average treatment effect on the treated)

Dependent variable	Treatment variable	Coefficient	p-values
Delayed	PRI_co	0.0246	0.551
Abandoned	PRI_co	0.0205	0.529
Observations	1,116		
Other indep. var.	Firm size, Square firm size, Internal sources, Group, Sector dummies		

* p<0.10 *** p<0.10, ** p<0.05, * p<0.10, Treatment model: Probit

Table 11 - Differences among collaborating and non collaborating firms – Delayed and Abandoned (Nearest-neighbour matching. Average treatment effect on the treated)

Dependent variable	Treatment variable	Coefficient	p-values
Delayed	Collaboration	0.0907***	0.000
Abandoned	Collaboration	0.0247*	0.093
Observations	6,354		
Other indep. var.	Firm size, Square firm size, Internal sources, Group, Sector dummies		

*** p<0.10, ** p<0.05, * p<0.10

Table 12 - Differences among firms collaborating with PRI and firms collaborating with other subjects – Delayed and Abandonment (Nearest-neighbour matching. Average treatment effect on the treated)

Dependent variable	Treatment variable	Coefficient	p-values
Delayed	PRI_co	0.0127	0.754
Abandoned	PRI_co	-0.0084	0.794
Observations	1,116		
Other indep. var.	Firm size, Square firm size, Internal sources, Group, Sector dummies		

*** p<0.10, ** p<0.05, * p<0.10

Appendix A

In this Appendix we provide details about the principal component analysis on the hampering factors of innovation to obtain the synthetic measures employed in the paper. Our synthetic 'hampering' variables are obtained by extracting the common variance from the original (and related) variables denoting 'hampering factors' [3].

As shown by table A1-A3, the original variables concerning cost, knowledge and market factors respectively are highly correlated: correlation coefficients are almost always above 0.5 (but for one case in which the correlation is about 0.49). This fact justifies the application of a Principal component analysis.

Table A1 - Matrix correlation for Cost factors

	Lack of internal funds	Lack of external finance	Cost of innovation too high
Lack of internal funds	1.000		
Lack of external finance	0.6546	1.000	
Cost of innovation too high	0.5361	0.5329	1.000

Table A2 - Matrix correlation for Knowledge factors

	Lack of qualified personnel	Lack of information on technology	Lack of information on materials
Lack of qualified personnel	1.000		
Lack of information on technology	0.6183	1.000	
Lack of information on materials	0.4872	0.6454	1.000

Table A3 - Matrix correlation for Market factors

	Market dominated by incumbent firms	Uncertain demand for innovative products
Market dominated by incumbent firms	1.000	
Uncertain demand for innovative products	0.5072	1.000

[3] We remind that the classification of hampering factors in homogenous categories is made by CIS survey. We followed the original CIS classification with the exception of the variable *Problem in finding cooperation partners.* CIS IV includes this variable among knowledge factors. We decided to keep it aside because of the relevance of this variable in our context.

In Table A4 we present the results of the principal component analysis. We notice that the first components (that we use as the synthetic measures for the hampering factors) have associated eigenvalues greater that one. Our choice to retain only the first component is in accordance with a widely used 'retaining' rule (the so-called Kaiser-Guttman criterion) according to which the retained components must have associated eigenvalues greater than one. Indeed in our situation all the first components have associated an eigenvalue greater than one and the other components have associated eigenvalues far below the unity. Moreover, the proportion of variance explained by the first components is high enough (above than 70%). Therefore the application of the Principal component analysis allows us to reduce the number of variables while retaining a relevant part of the original information.

Table A4 - Principal component analysis for Cost Knowledge and Market factors (unrotated)

	Cost factor		**Knowledge factors**		**Market factors**	
	Eigenvalue	Proportion of variance explained	Eigenvalue	Proportion of variance explained	Eigenvalue	Proportion of variance explained
First component	2.1510	0.7170	2.1699	0.7233	1.5072	0.7536
Second component	.5036	0.1679	.5139	0.1713	.4927	0.2464
Third component	.3453	0.1151	.3162	0.1054	.	.
Observations	6,355		6,355		6,355	

Appendix B

In this Appendix we provide some descriptive statistics of the dependent variables for the industry dummies. In the empirical analysis we use six industry dummies: Manufacturing high-tech, Manufacturing low-tech, Other industries, Knowledge intensive services, Other services, Retail. The variable Retail is used as reference in the empirical analysis. In constructing such industry dummies we follow the Eurostat classification for knowledge intensive sectors and the OECD classification for manufacturing industries. In particular in Manufacturing high-tech we included what OECD classified as High-technology industries and Medium-high-technology industries and in Manufacturing low-tech we add up those industries OECD classifies as Medium-low-tech industries and Low-tech-industries.

Tables B1 and B2 confirm the relevance of sectors in influencing the probability of collaborating in innovative projects. They also show a significant difference in delaying or abandoning projects between collaborating and not collaborating firms. The same difference is not significant when comparing firms collaborating with PRI with the other collaborating firms.

At the end, Table B3 reports the classification of the aggregates of sectoral dummies taken from 2 digit level of the NACE classification. With reference to the sectoral dummies Manufacturing high-tech and Manufacturing low-tech, we follow the OECD classification of manufacturing industries (see *www.oecd.org/sti/ind/48350231.pdf*). In particular, we grouped together High-technology industries and Medium-high-technology industries in Manufacturing high-tech, and grouped together Medium-low-technology industries and Low-technology industries in Manufacturing low-tech. With reference to the sectoral dummy Knowledge intensive services, we followed the Eurostat classification (see http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/htec_esms_an3.pdf).

Table B1

Variable: Delayed	Non collaborating firms (1)		Collaborating firms (2)		Firms collaborating with PRI (3)		Mean difference[a]	
	Mean*	Std. Dev.	Mean*	Std. Dev.	Mean	Std. Dev.	(2)-(1)	[b]
Manufactur high-tech	.5973 (822)	.4907	.6357 (291)	.4820	.6826 (167)	.4668	.	*
Manufactur low-tech	.4469 (1688)	.4973	.5247 (223)	.5005	.5340 (103)	.5013	**	.
Other industries	.4004 (949)	.4902	.5682 (132)	.4972	.5714 (49)	.5000	***	.
Knowledge intensive services	.4366 (868)	.4962	.6343 (309)	.4824	.6769 (130)	.4695	***	.(*)
Other services	.3757 (378)	.4849	.4054 (74)	.4943	.2500 (20)	.4443	.	. (*)
Retail	.3951 (534)	.4893	.5287 (87)	.5021	.6111 (18)	.5016	*	.

*N. of observations in parentheses

[b] mean difference between firms collaborating with PRI and firms collaborating with other subjects

Table B2

Variable: Abandoned	Non collaborating firms (1)		Collaborating firms (2)		Firms collaborating with PRI (3)		Mean difference[a]	
	Mean*	Std. Dev.	Mean*	Std. Dev.	Mean*	Std. Dev.	(2)-(1)	[b]
Manufactur high-tech	.1241 (822)	.3299	.1718 (291)	.3779	.1916 (167)	.3947	**	.
Manufactur low-tech	.0681 (1688)	.2520	.1390 (223)	.3467	.1262 (103)	.3337	***	.
Other industries	.0622 (949)	.2416	.0606 (132)	.2395	.0816 (49)	.2766	.	.
Knowledge intensive services	.0772 (868)	.2670	.1197 (309)	.3252	.11538 (130)	.3207	**	.
Other services	.0979 (378)	.2975	.1081 (74)	.3126	.2000 (20)	.4104	.	. (*)
Retail	.0318 (534)	.1757	.0230 (87)	.1507	.0555 (18)	.2357	.	.

*N. of observations in parentheses

[b] mean difference between firms collaborating with PRI and firms collaborating with other subjects

Table B3

Aggregation of sectoral dummies	2 digit level NACE classification (rev. 1.1)
Manufacturig low-tech	15, 17, 18, 19, 20, 21, 22, 23, 25, 26, 27, 28, 36, 37
Manufacturing high-tech	24, 29, 30, 31, 32, 33, 34, 35
Other industries	10, 40, 45
Retail	50, 51, 52
Other services	55, 60, 63
Knowledge intensive services	61, 62, 64, 65, 66, 67, 70, 71, 72, 73, 74