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Pain shared, pain halved? Cooperation as a coping strategy for innovation barriers

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Abstract The paper analyses the relationship between the perception of barriers to innovation and the firm's propensity to cooperate to mitigate their effect. First, we look at whether cooperation with research organizations or private firms is associated with experiencing different types of barriers, for example, financial constraints, lack of human capital or uncertain market demand. Second, we test whether experiencing several types of barriers simultaneously has a super-modular effect on the propensity to cooperate *tout court,* and the choice of cooperation partner. We find that having to face a single, specific constraint leads to firms 'sharing the pain' with cooperation partners—both research organization and other firms. However, the results of a super-modularity test show that having to cope with different barriers is a deterrent to establishing cooperation agreements, especially when firms lack finance, adequate skills and information on technology or markets. The paper adds to the innovation literature by identifying the factors associated with firms' coping with different barriers by applying a selective cooperation strategy.

Keywords Barriers to innovation · Innovation cooperation · Super- and sub-modularity · Firm behaviour · Innovation policy

JEL Classification 032 · 031

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1 Introduction and Background

Since the late 1990s, a flourishing literature on cooperation for innovation has focused on different *forms* of collaborations among actors. These collaboration types range from research joint ventures, non-equity contractual collaborations and joint projects, to formal and informal arrangements (Hagedoorn et al. 2000; Gallié and Roux 2010), both among private firms and between private firms and public research organizations. In terms of the *object* of cooperation, the majority of this literature looks at cooperation within the realm of R&D projects, which usually are considered more costly and more risky (Kleinknecht and Reijnen 1992; David and Hall 2000; Fritsch and Lukas 2001; Miotti and Sachwald 2003; López 2008).

Analyses of the mechanisms that govern cooperation for innovation are based on different theoretical perspectives. The industrial organization literature (e.g. Kaiser 2002) suggests that incentives to cooperate are associated with strategies to internalize knowledge that can leak out to competitors (Arvanitis 2012). The management literature shows that firms decide to cooperate if they can foresee opportunities to shape the competitive environment, upgrade capabilities, gain access to new resources and learn to use new/complex technologies (Caloghirou et al. 2003). Relatedly, the large scholarship on absorptive capacity following the seminal work by Cohen and Levinthal (1989, 1990), identifies mechanisms that enable firms to exploit externally acquired knowledge (e.g. Zahra and George 2002; Franco et al. 2014). Overall, as suggested by de Faria et al. (2010, p. 1083), the decision to cooperate is based on how firms "manage the trade-off between generating and receiving knowledge spillovers to and from partners", and depends on the type of partner, the absorptive capacity of the cooperating firm and the type of innovation involved (de Faria et al. 2010).

The above theoretical perspectives tend (with a few exceptions) more often to associate incentives to cooperate with potential gains in terms of learning and knowledge spillovers rather than the potential opportunities to minimize a loss or cope with a problem.[1] However, none of these literature streams considers experiencing barriers to innovation as an incentive to cooperate.

Within the recent and burgeoning literature on the barriers to innovation, several contributions look at: (i) firm characteristics affecting the perception of financial and non-financial obstacles to innovation (D'Este et al. 2012, 2014; Hölzl and Janger 2013, 2014; Pellegrino and Savona 2013); (ii) the deterrent effect of obstacles on firms' decisions to engage and invest in innovation activity, and the propensity to innovate (Mohnen and Rosa 2002; Baldwin and Lin 2002; Galia and Legros 2004; Canepa and Stoneman 2008; Tiwari et al. 2008; Savignac 2008; Iammarino et al. 2009; Mancusi and Vezzulli 2010); and (iii) the direct and indirect impact of barriers on firms' productivity and performance more generally (Coad et al. 2016) (see Hall et al. 2016, for a recent review on the subject).

The extant literature on the barriers to innovation has missed the opportunity to look at whether and how firms *change their strategy in response to their perception of obstacles*. Also, while contributions on barriers have focused on the *direct effect* of barriers on firms' innovation engagement and performance, they have not explored the *indirect effect* that

[1] For instance, from an industrial organization perspective, López (2008) finds that a cost-risk sharing strategy is the main determinant of cooperation in R&D projects in the case of Spanish firms. Barge-Gil (2010, p. 198) posits that "Cooperation for innovation is more important for firms required to overcome more obstacles in its pursuit".

barriers might induce on performance through a change in the firm's strategy, for example, increasing their cooperation with different partners.[2]

This paper aims to contribute to the cooperation and the barriers to innovation literature by addressing the gap identified above. We look at whether cooperation might be a viable strategy to cope with financial and non-financial (knowledge or market related) barriers[3] and whether the choice of cooperation partner(s) is associated with experience of a particular barrier or, indeed, the simultaneous presence of several different barriers.

Specifically, the first aim is to ascertain whether, *ceteris paribus*, firms that experience financial and non-financial obstacles to innovation engage more in cooperation, and 'share the pain' of specific bottlenecks in the attempt to innovate. Cooperation can be an important strategy for coping with cost-related barriers. The literature shows that collaboration with external partners can produce cost- and risk-sharing opportunities (Hagedoorn et al. 2000; López 2008). These reduce internal financial constraints and, through the pooling of risk, the cost of external funding. Cost-related constraints can be further attenuated through economies of scale and scope, which are likely to arise from collaboration with external partners (Becker and Dietz 2004; Arvanitis 2012). The decision to engage in cooperation can be dictated also by the need to handle internal knowledge and skills shortages. Partnering with other firms or research organizations can grant access to crucial knowledge that is not available within the focal firm (Barge-Gil 2010), and can lead to upgrading of competences and skills (Caloghirou et al. 2003). Furthermore, firms can benefit from knowledge sharing and complementarities, which allow for the use of parallel and wider knowledge packages, whose development and maintenance might be too difficult for firms innovating in isolation (Ahuja 2000). Finally, cooperation can represent a viable strategy for coping with market related barriers. Collaboration for innovation might raise appropriability issues, which could erode the firm's competitive advantage (Cassiman and Veugelers 2002; Veugelers and Cassiman 2005). However, cooperation can also increase the firm's capacity to enter new markets, reposition and expand in existing ones, capture technological information to face changes in demand and bring technologies to the marketplace rapidly (Mowery et al. 1998; Hagedoorn et al. 2000; Wu 2012). Given the above, we address the following research question:

Q1 Do barriers to innovation lead to cooperation?

With respect to Q1, our conjecture is that facing cost, knowledge and market related barriers increases the proclivity to resort to cooperation as a coping strategy, particularly to share the costs and risks of innovative activities and to outsource to compensate for assets that are lacking when engaging in innovation.

Our second objective is to ascertain whether experiencing a specific type of barrier (related, e.g., to cost, knowledge or market) leads, *ceteris paribus*, to engagement with a specific type of partner (e.g. customers, research organizations). As mentioned above, the cooperation literature has been looking at cooperation beyond the realm of R&D activities, based on engagement with a variety of partners (Belderbos et al. 2004, 2006). This broader

[2] A notable exception is D'Este et al. (2014), which looks at how firms reduce the barriers to innovation by increasing their training expenditures.

[3] Section 2 and Table 1 describe at greater length the types of financial, knowledge and market obstacles included in European innovation survey questionnaires and used in this work. In particular we refer to cost barriers (lack of internal funds, lack of external funds, or excessive cost related to innovation); demand and market structure barriers (demand uncertainty or a market structure dominated by incumbent large firms); knowledge barriers (lack of skilled personnel, lack of information on markets, or lack of information on technologies).

view of cooperation identifies firm characteristics that influence the different propensity of firms to cooperate with 'specialized knowledge suppliers' (Tether 2002; Schmidt 2005; Tether and Tajar 2008a, b). The spatial, social and cognitive proximity with external partners, alongside the degree of engagement in innovative activities, either R&D or non-R&D related (D'Este et al. 2013), affect not only the propensity to cooperate but also the choice of partners. Evidence suggests that choice of partner or partners depends on two different strategies: (i) firms seeking to benefit from horizontal spillovers and aiming to define technological trajectories that are new to the firm or the market, tend to choose universities, or public or private research organizations; (ii) firms that want to build incrementally on their existing knowledge and to benefit from vertical spillovers will instead choose customers and suppliers as cooperation partners (Barge-Gil 2010; De Faria et al. 2010). On the above premises, we address the following research question:

Q2 Do different barriers lead to collaboration with specific cooperation partners?

Our conjecture on Q2 is that the choice of partner is dictated by the coping strategy for the specific problem(s) encountered. While we expect that finance barriers can be alleviated by sharing costs with any type of partner, knowledge and skills shortages may lead firms to prioritize cooperation with research organizations. Market uncertainty might lead to cooperation with customers and suppliers rather than competitors or research organizations.

Our third objective is to investigate whether the perception of several different barriers simultaneously might *complement* (*super-modular* effect) or *substitute (sub-modular* effect*)* the decision to cooperate. Indeed, it is likely that firms will experience the joint presence of more than one barrier. Scholars have investigated cooperation failures (Lhuillery and Pfister 2009) and the obstacles to cooperation (Mora Valentín 2000), which hint at the possible bottlenecks to intensifying cooperation as a response to multiple barriers. A particularly novel aspect of our contribution is the specific focus on the presence of a super- or sub-modular effect of barriers on cooperation, which is an adaptation to the methodological framework proposed by Mohnen and Röller (2005), who examine complementarity in innovation policy instruments using evidence on obstacles. This leads to our third research question:

Q3 Are the perceived barriers complements or substitutes as determinants of cooperation activities?

Due to the scant prior related work, we do not formulate explicit expectations about Q3. We rely on our empirical application to shed light on the complementarity/substitutabiliy effect of barriers on the propensity to cooperate.[4]

We address Q1–Q3 empirically by drawing on the fourth wave of the French Community Innovation Survey 2002–2004 (French CIS4). Results show that experiencing barriers is associated with the adoption of cooperation strategies. Financial barriers are positively related to all types of cooperation. Thus, firms resort to cooperation, first and foremost, as part of a risk and cost-sharing strategy. It emerges also that knowledge obstacles trigger cooperation with research organizations: as expected, firms collaborate with research institutes and universities to mitigate shortages of skills and competencies. In addition, results provide robust support for the absence of super-modularity and the

[4] Whether cooperation exacerbates innovation barriers or reduces them is an aspect that represents a future extension of our research. Here, the analysis is limited to the effect of one or more barriers on the cooperation decision.

presence of substitutability effects from the perception of several barriers simultaneously. While a firm experiencing a specific obstacle is prone to "share the pain" with partners, the experience of several barriers jointly does not exert a cumulative effect; there is no evidence of cooperation intensification. On the contrary, the joint presence of knowledge and financial obstacles, in particular, reduces the propensity to cooperate. A spectrum of innovation obstacles, which includes knowledge shortages and, thus, possibly involves low absorptive capacity, might lead firms to refocus on internal activities, thereby reducing cooperation.

The questions addressed in this paper and our findings are highly relevant for policy. From the perspective of extant theoretical framework(s) for innovation policy and as pointed out by Coad et al. (2016), we do not consider policies to reduce the barriers to innovation as typical cases of fixing market failures (Arrow 1962). Rather, our analysis contributes to a better understanding of policies aimed at dealing with system failures (e.g., Woolthuis et al. 2005; Metcalfe 2005). Indeed, the case for mitigating interaction failures among innovation system organizations—firms and research organizations—is reinforced by evidence on whether cooperation allows firms to cope with innovation barriers.

The remainder of the paper is organized as follows. In Sect. 2 we describe the data and the empirical strategy. In Sect. 3 we present and discuss our results. Section 4 concludes.

2 Data and empirical strategy

We focus on the case of France. Robin and Schubert (2013) provide an interesting comparative narrative on the French context in terms of public research institutes. France, historically, has been characterized by a centralized and mission-oriented science and technology policy, where missions are defined at the central level and implemented by national, publicly funded research centres such as CNRS, INRA, INRIA and INSERM. Interestingly, for the purposes of our work, until 2006 (under the Act of Law of 12 July, 1999) the National Research Agency (ANR) did not provide explicit public financial support for collaborative research projects involving public research organisations and private firms (Robin and Schubert 2013). Because our empirical investigation is based on data from the French CIS4,[5] our empirical findings unravel the tendency for firms to cooperate for innovation before and regardless of the introduction of the 2006 tax credit regulation.

The CIS is conducted in EU countries, using a EUROSTAT harmonized questionnaire based on the OECD Oslo Manual (OECD 2005). The French CIS4 was launched in 2005. It targeted a representative sample of firms with more than 10 employees, in non-agricultural sectors; 25,000 firms were interviewed, a response rate of around 86%.[6] The majority of French CIS4 variables cover the 3-year period 2002–2004; some information on firm structure (e.g., employment, turnover) refer to the initial and final years of the period, and innovation expenditure and outcome variables refer to 2004.

[5] In this respect, note also that the French CIS2008 (focusing on years 2006–2008) did not include information on barriers, the French CIS2010 (focusing on years 2008–2010) concentrated on a period largely affected by the global economic crisis, the French CIS2012 (2010–2012) did not include information on barriers and focused on a period partially affected by the crisis, the French CIS2014 (2012–2014) was not available at the time of the writing.

[6] See http://www.insee.fr/sessi/enquetes/innov/cis4/cis4.htm and http://www.insee.fr/sessi/4pages/222/principal.htm (last accessed: May 2016) for more information.

Although we rely only on cross-sectional data, the French CIS4 questionnaire includes a wealth of information covering firms' structure and location, innovation inputs, outputs and outcomes, and—most importantly for our analysis—innovation barriers and cooperation with external partners. The last two items are important because they allow us to retrieve information on both cooperation and barriers in a period (i.e. 2002–2004) when perception of obstacles was less likely to be affected by the (probably unobservable) confounding and, thus, biasing, factors related to the last global economic crisis.

In what follows, we focus on manufacturing firms only. Given the filtered structure of the CIS questionnaire and in order to have complete information for all the firms included in our sample, we restrict our sample to innovative firms with no missing values for the variables employed (see Mairesse and Mohnen (2010) for a discussion on the opportunities and constraints from the CIS filtering).[7] Our working sample includes 3825 firms.

We exploit a twofold econometric strategy. First, we investigate whether and how specific barriers linked to cost, market and knowledge factors are related to specific types of cooperation. To this end, we estimate a series of probit models as follows:

$$Cooperation_i = a + b_1\boldsymbol{X}_i + b_2\boldsymbol{Barriers}_i + \varepsilon_i.$$

where *Cooperation* denotes the dependent variable the firm's cooperation agreements with different types of partners; $\boldsymbol{X}$ is a vector of appropriate control variables; ***Barriers*** is a vector of the variables synthesizing specific types of obstacles to innovation perceived by the firm; and ε is the error term. A further, augmented specification includes the interaction terms between pairs of barriers in order to obtain a preliminary sense of the potential influence of the joint perception of barriers on the propensity to cooperate.

Our dependent variables refer to the firm's engagement in innovation cooperation. We employ a general binary variable, *COOP*, which captures whether the firm is engaged in formal cooperation with any type of partner. We distinguish between cooperation with firms (*COOPFIRM*) and research organizations (*COOPORG*). As mentioned in Sect. 1, the choice of partner might be dictated by different incentives, such as cost and risk sharing or outsourcing of information on technologies.

Key explanatory variables include a set of dummies that indicate perception of obstacles to innovation. These binary variables are built on the 4-point likert scale items included in the CIS questionnaire, and take the value 1 if the firm reports high relevance for the influence of at least one item related to: costs (COST) (lack of internal funds, lack of external funds, or excessive cost related to innovation); demand and market structure (MKT) (demand uncertainty or market structure dominated by incumbent large firms); knowledge (KNOW) (lack of skilled personnel, lack of information on markets, or lack of information on technologies). It is important to remember that the barrier variables synthesize perception of their importance for innovation-active firms (i.e., firms that have engaged in innovation): in this respect, according to the classification proposed in D'Este et al. (2012) and used in other studies, we focus on the *revealed* rather than the *deterring barriers,* which are the hampering factors encountered in the production of innovations, rather than obstacles that deter firms from engaging in innovation activities (D'Este et al. 2008, 2012; Pellegrino and Savona 2013; Hölzl and Janger 2013, 2014).

[7] The structure of the CIS in most European countries includes a filter on questions related to the innovative behaviour of firms: while questions on the barriers to innovation are addressed to both innovative and non-innovative firms (e.g., those declaring they had (had not) introduced a product or process innovation), questions on cooperation are addressed only to firms stating they introduced a product or process innovation or engaged in innovation activities.

Table 1 List of variables

Variable name	Description
COOP	Engagement in innovation cooperation agreements (D)
COOPFIRM	Cooperation with other firms (Other firms in the same group, Suppliers, Customers, Competitors) (D)
COOPORG	Cooperation with research organisations (Private R&D institutes and labs, Universities, Public research organisations) (D)
COST	Highly relevant barriers related to: lack of internal funds OR lack of external funds OR excessive cost related to innovation (D)
KNOW	Highly relevant barriers related to: lack of skilled personnel OR lack of information on markets OR lack of information on technologies (D)
MKT	Highly relevant barriers related to: demand uncertainty or market structure dominated by incumbents (D)
SIZE	Log-transformed number of employees in 2002
GROUP	Firm belonging to an industrial group (D)
TNC	Affiliate to a foreign group (D)
R&D Funding	Receipt of public funding to innovation (regional, national or EU level) (D)
R&D Continuous	Engagement in continuous R&D (D)
Export	Export to foreign markets (D)

Variables are defined over the reference period 2002–2004, unless differently specified; (D): dummy variable

Building on these variables, we create a set of interactions to provide a preliminary picture of whether and how different types of barriers are complements influencing the cooperation propensity. To this end, we constructed the interactive variables COST*MKT, COST*KNOW and MKT*KNOW, which we add to the baseline specification to address the first two research questions.

The control variables in $\boldsymbol{X}$ aim to reduce potential omitted variable bias. First, we control for firm size, measured as the logarithm of employment. Size can be related to cooperation since large firms are more likely to adopt a combined strategy of internal and external knowledge acquisition (Veugelers and Cassiman 1999) due to their critical mass, resources and likely higher capacity to manage cooperation agreements effectively (Belderbos et al. 2004; Segarra-Blasco and Arauzo-Carod 2008).

We control also for technological capability, by including a dummy variable (i.e. R&D Continuous), which captures continuous engagement in R&D investment (e.g., presence of a dedicated department). This may exert a positive effect on the propensity to cooperate (e.g. Colombo and Garrone 1996; Cassiman and Veugelers 2002; Belderbos et al. 2004). Indeed, persistent and sustained engagement in R&D reflects higher absorptive capacity (Cohen and Levinthal 1989), higher capacity to take advantage from cooperation and thus to recognize its strategic value.

We control for the effect of public funding (R&D Funding) on the probability to cooperate since innovation policy programmes may explicitly require firms to cooperate (e.g. in the case of collaborative R&D subsidies). Public support can change the strategic behaviours of beneficiaries and how they conduct their R&D and, eventually, might lead to increased cooperation with external partners (Marzucchi et al. 2015).

Two dummies for whether firms belong to a national group (GROUP) or to a transnational corporation (TNC) are included. Firms belonging to a group, either national

Table 2 Descriptive statistics

Variable	N	Mean	SD	Min	Max
COOP	3825	0.475	0.499	0	1
COOPFIRM	3825	0.448	0.497	0	1
COOPORG	3825	0.279	0.449	0	1
COST	3825	0.411	0.492	0	1
KNOW	3825	0.244	0.430	0	1
MKT	3825	0.289	0.453	0	1
Size	3825	4.852	1.432	0	11.324
Group	3825	0.435	0.496	0	1
TNC	3825	0.266	0.442	0	1
R&D funding	3825	0.407	0.491	0	1
R&D continuous	3825	0.547	0.498	0	1
Export	3825	0.822	0.383	0	1

or international, are expected to be more likely to cooperate. When looking for partners, they benefit from the power and prestige of the wider group. In addition, firms belonging to foreign groups may need to establish cooperation agreements in order to acquire specific local knowledge and capabilities, for instance, related to local markets requirements (e.g. Tether 2002). Moreover, they may exploit intra-group communication channels and knowledge pools to gather more information about potential partners, create easier contacts and more easily tap into knowledge from the interacting firms or organizations (Tether 2002; Mohnen and Hoareau 2003).

We include firms' engagement in international markets (EXPORT) which might exert an effect on cooperation. On the one hand, exporting firms may revert to cooperation to acquire capabilities and maintain their competitiveness. On the other hand, when faced with a strong competitive environment, exporting firms may be induced to protect their know-how (Cassiman and Veugelers 2002) and may reduce cooperation in order to minimize knowledge leakages.

Finally, we include two sets of dummies. The first is the firm's regional location (NUTS 2).[8] It accounts for regional heterogeneity in terms of availability of cooperating partners and structural, institutional and social aspects, which might affect the propensity for cooperation (for an interesting take on this issue, see D'Este et al. 2013). Institutional features can provide different grounds for cooperation activities because of the different formal and informal instruments at the regional/local level to stimulate cooperative activities between firms and other institutional actors such as universities and research centres (Robin and Schubert 2013). Also, some regions are more industrialized than others, providing firms with a large 'reservoir' of partners to choose for cooperation activities. Moreover, the cognitive distance among cooperating partners may be shorter if partners are located within the same regional borders, making it easier for the same partners to cooperate. Overall, each region has idiosyncratic specificities that can influence the propensity of embedded firms to cooperate. The second is a set of NACE 2-digit dummies to control for sector specificities.

[8] We exclude from our sample firms located in the French overseas territories since the availability of suitable cooperating partners in the proximity might be very limited for these firms.

Table 3 Correlation matrix

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
(1)	COOP	1											
(2)	COOPFIRM	0.9477	1										
(3)	COOPORG	0.6551	0.5717	1									
(4)	COST	0.0082	0.0049	0.0446	1								
(5)	KNOW	−0.0103	−0.0178	0.0054	0.1993	1							
(6)	MKT	0.0276	0.027	0.0417	0.1903	0.2128	1						
(7)	Size	0.264	0.2663	0.2802	−0.1186	−0.1136	−0.023	1					
(8)	Group	0.0654	0.0713	0.0617	−0.0408	−0.0182	−0.0159	0.1349	1				
(9)	TNC	0.1276	0.1389	0.0832	−0.0753	−0.0828	−0.0186	0.3539	−0.5272	1			
(10)	R&D funding	0.1921	0.1657	0.3007	0.0256	−0.008	0.0368	0.1205	0.043	−0.0576	1		
(11)	R&D continuous	0.2365	0.2288	0.2795	−0.0273	−0.0273	0.0262	0.3229	0.0648	0.1306	0.2716	1	
(12)	Export	0.1428	0.139	0.1482	−0.0418	−0.0489	0.0099	0.2807	0.0164	0.2072	0.1202	0.2304	1

Our working variables are presented in Table 1, with descriptive statistics reported in Table 2. Table 3 presents the correlation matrix, which does not suggest relevant collinearity issues.

The second part of our empirical analysis addresses the third research question, that is, whether there is a super- or sub-modular effect of the perception of barriers on cooperation activities. This requires a series of complementarity tests (Antonioli et al. 2013; Hottenrott et al. 2014) which allow us to exploit the formalization of complementarities for discrete cases (Mohnen and Röller 2005) examining the presence of complementarity (super-modularity) or substitutability (sub-modularity) among barriers that do not emerge directly from the analysis of simple interaction terms. In order to implement the tests we consider the 'cooperation function' of firm j ($\mathrm{COOP_j}$) as the firm's objective function and focus on two types of barriers at a time that might affect the firm's cooperation function, b' and b'':[9]

$$COOP_j = COOP_j(b', b'', \theta_j) \forall j.$$

Each firm j faces a combination of the two barriers, (b', b'') and a set of endogenous and exogenous controls θj, including the remaining barrier.

Complementarity between the two different barriers can be analysed by testing whether $COOP_j(b', b'', \theta_j)$ is super-modular in b' and b''. Our aim is to derive a set of inequalities to be tested in the empirical analysis.

Each firm might be in one of the four following states of the world: facing both $b^{'}$ and $b^{''}$; neither of the two; or one, but not the other one; and vice versa. This leads to four consequent elements in the set B (forming a *lattice*):

$$B = \{\{00\}, \{01\}, \{10\}, \{11\}\}.$$

It is possible to demonstrate that b' and b'' are complements and, hence, $COOP_j$ is super-modular if and only if:

$$COOP_j(11, \theta_j) + COOP_j(00, \theta_j) \geq COOP_j(10, \theta_j) + COOP_j(01, \theta_j),$$

Or

$$\begin{aligned} COOP_j(11, \theta_j) - COOP_j(00, \theta_j) \geq & \left[COOP_j(10, \theta_j) - COOP_j(00, \theta_j)\right] \\ & + \left[COOP_j(01, \theta_j) - COOP_j(00, \theta_j)\right] \end{aligned}$$

This second inequality clearly shows the interpretation of the super-modularity, or complementarity between two barriers. If the inequality holds, it means that the gain in the propensity to cooperate (increase in the probability to cooperate) that the firm achieves by moving from a state of the world characterized by the absence of relevant barriers (0,0) to a state of the world in which both barriers are perceived as relevant (1,1), is higher than the sum of the gains in the propensity to cooperate (increases in the probability to cooperate) obtained by moving from a state of the world (0,0) to those in which only one barrier is perceived as relevant (1,0) and (0,1).

[9] We confine our analysis to the inclusion of two pairs of barriers at a time, given the complexity in interpreting the implications highlighted for policy. To the best of our knowledge, a complementarity test, based on inequality restrictions, on three or more variables (e.g. triplets, quadruplets), has never been implemented. In addition, and again to the best of our knowledge, in STATA (the statistical software we used for the analysis) there is no routine that allows joint testing of several inequality restrictions, on pairs of variables (i.e. not triplets or quadruplets), as Mohnen and Röller (2005) do using a routine in GAUSS.

In order to test for complementarities or substitution effects we operationalize the methodological framework in two steps.

In the first step we set up the 'Cooperation function', which can be specified as follows, using two types of barriers, e.g. COST and MKT,[10] to define the states of the world, while controlling for both the third barrier (e.g., KNOW) and the set of control variables defined above:

$$\begin{aligned}[\mathrm{COOP}]_i = {} & b_{0i}[\mathrm{Controls}] + \mathbf{a}\mathrm{KNOW} \\ & + \mathbf{b}_{1i}[\mathrm{COST}(1)/\mathrm{MKT}(1)] \\ & + \mathbf{b}_{2i}[\mathrm{COST}(1)/\mathrm{MKT}(0)] \\ & + \mathbf{b}_{3i}[\mathrm{COST}(0)/\mathrm{MKT}(1)] \\ & + \mathbf{b}_{4i}[\mathrm{COST}(0)/\mathrm{MKT}(0)] + u_i\end{aligned}$$

Both the cooperation variable (COOP) and the two types of cooperation (COOPORG and COOPFIRM) are dummy variables: therefore, we run a set of probit regressions, excluding the constant term, since we are interested in the marginal effects associated with all the four states of the world b_1, b_2, b_3 and b_4. It is important to stress that while we focus on the complementarity between two types of barriers (e.g. COST and MKT), we control for a third type of obstacle (e.g. KNOW). Specifically, the marginal effects associated with the four states of the world used in the complementarity test are computed setting at 0, 1, the mean value and excluding the third barrier. This allows us to infer whether the results of the complementarity between two barriers typologies test hold for the different values of the third type of obstacle.

Having retrieved the marginal effects using the probit estimates, the next step is to implement a set of *Wald tests*, which allow us to test the following linear restriction on the state-of-the-world-dummies' marginal effects: $b_1 + b_4 = b_2 + b_3$ where b_1 is associated with the (1,1) state of the world; b_2 is associated with the (1,0) state of the world; b_3 is associated with the (0,1) state of the world and b_4 is associated with the (0,0) state of the world.

The *Wald tests* are distributed as a χ^2 with one degree of freedom since we are testing a single linear restriction at a time. Given that we are interested in the following inequalities, $b_1 + b_4 - b_2 - b_3 \geq 0$; $b_1 + b_4 - b_2 - b_3 \leq 0$, and since each Wald test has one degree of freedom, we can apply the appropriate procedure for the *p* value adjustment in testing inequalities.[11] Moreover, as a further robustness check, we combine the results of the 'adjusted' Wald test with the resulting sign of the linear combination of the coefficients.

By looking at the joint sets of results, we can infer whether rejection of the Wald test null hypothesis allows us to identify complementarity or substitutability between barriers: on the one hand, if $b_1 + b_4 - b_2 - b_3 \geq 0$ and the *Wald test* leads us to reject the null, we can argue that we are in presence of super-modularity and, hence, of complementary barriers; on the other hand, we infer sub-modularity if $b_1 + b_4 - b_2 - b_3 \leq 0$ and the *Wald test* null is also rejected.

[10] The same reasoning holds for other couples of barriers.

[11] See http://www.stata.com/support/faqs/statistics/one-sided-tests-for-coefficients/.

3 Results

3.1 Baseline probit

The results of our baseline probit are reported in Table 4, with the marginal effects reported in Table 5. We test six specifications of the baseline probit. The models test the effect of our main regressors and control variables respectively on:

1. The probability of engaging in cooperation *in general* (models 1 and 4), which responds to our first research question (Q1) about whether experiencing barriers of any type is associated with the propensity to cooperate;
2. The probability to cooperate with other firms (models 2 and 5);
3. The probability to cooperate with research organizations (models 3 and 6). The last two points respond to our second research question (Q2).

The first triplet of models (1–3) includes proxies for single barriers only; the second triplet (models 4–6) also includes the interaction terms. More specifically, as mentioned above, we check whether experiencing financial constraints, lack of knowledge or market structure barriers affects the probability of cooperating in general and with specific partners (models 1–3); we test also whether facing joint obstacles (in pairs) increases the chances of cooperating (in general, and with specific partners) or, rather, deters firms from cooperating as much as they might had they experienced only a single barrier. We reprise this latter issue within a complementarity test, which allows us to investigate further whether a positive (negative) effect, emerging from the interactive dummies, translates into an augmenting/super-modular (diminishing/sub-modular) effect of joint obstacles on the propensity to cooperate in general, and with specific partners (which responds to our third research question Q3).

Indeed, in our discrete setting, the tests for complementarity are more informative than the probit results. In our case, it is not possible to impose continuity on the variables capturing the barrier perception and investigating complementarities through the analysis of mixed partial derivatives (Milgrom and Roberts 1995). However, we are able to test whether perceiving one barrier increases more (or less) the propensity to cooperate, in case the perceived relevance of the other barrier increases. The complementarity test might, in turn, add more fine-grained insights. For instance, as we will see in the following—in the case of knowledge and market barriers for cooperation, in general and with other firms—while the interaction terms point to non-significant effects, the complementarity test may reveal the presence of sub-modularity. In this case, our test points to a situation in which perceiving both barriers increases the probability of cooperation less than if the firm perceives single barriers.

Turning to the presentation of the results, the first piece of evidence is that experiencing financial barriers is a robust, significant driver of cooperation, both in general and across different partners. In line with the literature (de Faria et al. 2010; Barge-Gil 2010, among others), carrying out expensive innovation is a major driver of cooperation, which emerges as a cost-sharing strategy. Interestingly, the perception of relevant financial constraints seems to be related more robustly to a higher tendency to cooperate with research organizations.

In relation to cooperation with research organizations, one of our conjectures is confirmed: experiencing knowledge barriers linked to information on technologies and lack of qualified human capital, is associated with a positive and significant coefficient of

Table 4 Baseline probit estimations

	(1) COOP	(2) CCOPFIRM	(3) COOPORG	(4) COOP	(5) COOPFIRM	(6) COOPORG
COST	0.0829*	0.0817*	0.1873***	0.1672***	0.1496***	0.2732***
	(0.0453)	(0.0453)	(0.0499)	(0.0582)	(0.0581)	(0.0641)
KNOW	0.0560	0.0305	0.0997*	0.2785***	0.2434***	0.4036***
	(0.0521)	(0.0523)	(0.0572)	(0.0809)	(0.0813)	(0.0861)
MKT	0.0539	0.0597	0.0637	0.0928	0.0991	0.1146
	(0.0494)	(0.0495)	(0.0539)	(0.0730)	(0.0732)	(0.0802)
COST*KNOW				−0.3383***	−0.2957***	−0.4024***
				(0.1045)	(0.1048)	(0.1130)
COST*MKT				0.0096	0.0288	0.0581
				(0.0993)	(0.0991)	(0.1076)
KNOW*MKT				−0.1204	−0.1563	−0.2458**
				(0.1077)	(0.1078)	(0.1167)
SIZE	0.1464***	0.1368***	0.1914***	0.1472***	0.1373***	0.1928***
	(0.0187)	(0.0187)	(0.0209)	(0.0187)	(0.0187)	(0.0210)
GROUP	0.2173***	0.2744***	0.0984	0.2180***	0.2754***	0.0994
	(0.0565)	(0.0570)	(0.0644)	(0.0566)	(0.0571)	(0.0646)
TNC	0.2794***	0.3522***	0.0871	0.2823***	0.3555***	0.0902
	(0.0681)	(0.0682)	(0.0762)	(0.0683)	(0.0684)	(0.0765)
R&D Funding	0.3835***	0.3101***	0.6657***	0.3813***	0.3082***	0.6654***
	(0.0458)	(0.0458)	(0.0492)	(0.0459)	(0.0459)	(0.0493)
R&D Continuous	0.3086***	0.3012***	0.4245***	0.3040***	0.2968***	0.4182***
	(0.0471)	(0.0473)	(0.0532)	(0.0472)	(0.0473)	(0.0533)
Export	0.1078*	0.0909	0.1646**	0.1063*	0.0889	0.1627**
	(0.0614)	(0.0621)	(0.0733)	(0.0614)	(0.0621)	(0.0733)
Regional dummies	YES	YES	YES	YES	YES	YES
Sector dummies	YES	YES	YES	YES	YES	YES
_cons	−0.9801**	−1.1777***	−2.0285***	−1.0433**	−1.2346***	−2.1220***
	(0.4333)	(0.4191)	(0.4754)	(0.4279)	(0.4153)	(0.4678)

Table 4 continued

	(1) COOP	(2) CCOPFIRM	(3) COOPORG	(4) COOP	(5) COOPFIRM	(6) COOPORG
N	3825	3825	3821	3825	3825	3821
Pseudo R^2	0.105	0.103	0.171	0.107	0.105	0.176
ll	−2368.249	−2358.661	−1875.452	−2361.412	−2352.722	−1865.642
χ^2 (d.f.)	525.683 (51)	506.059 (51)	645.988 (50)	539.718 (54)	515.489 (54)	660.341 (53)
p value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Robust standard errors in parentheses

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 5 Baseline probit estimations (marginal effects)

	(1) COOP	(2) CCOPFIRM	(3) COOPORG	(4) COOP	(5) COOPFIRM	(6) COOPORG
COST	0.0330*	0.0323*	0.0587***	0.0666***	0.0591***	0.0854***
	(0.0180)	(0.0179)	(0.0156)	(0.0232)	(0.0229)	(0.0200)
KNOW	0.0223	0.0121	0.0312*	0.1109***	0.0961***	0.1262***
	(0.0207)	(0.0207)	(0.0179)	(0.0322)	(0.0321)	(0.0268)
MKT	0.0215	0.0236	0.0200	0.0369	0.0391	0.0358
	(0.0197)	(0.0195)	(0.0169)	(0.0291)	(0.0289)	(0.0251)
COST*KNOW				−0.1347***	−0.1168***	−0.1258***
				(0.0416)	(0.0414)	(0.0353)
COST*MKT				0.0038	0.0114	0.0181
				(0.0395)	(0.0391)	(0.0336)
KNOW*MKT				−0.0479	−0.0617	−0.0768**
				(0.0429)	(0.0426)	(0.0365)
SIZE	0.0583***	0.0540***	0.0600***	0.0586***	0.0542***	0.0603***
	(0.0074)	(0.0074)	(0.0065)	(0.0075)	(0.0074)	(0.0065)
GROUP	0.0865***	0.1083***	0.0308	0.0868***	0.1088***	0.0311
	(0.0225)	(0.0225)	(0.0202)	(0.0225)	(0.0225)	(0.0202)
TNC	0.1112***	0.1391***	0.0273	0.1124***	0.1404***	0.0282
	(0.0271)	(0.0269)	(0.0239)	(0.0272)	(0.0270)	(0.0239)
R&D funding	0.1527***	0.1225***	0.2086***	0.1518***	0.1217***	0.2080***
	(0.0182)	(0.0181)	(0.0153)	(0.0183)	(0.0181)	(0.0153)
R&D continuous	0.1229***	0.1189***	0.1330***	0.1210***	0.1172***	0.1307***
	(0.0187)	(0.0187)	(0.0165)	(0.0188)	(0.0187)	(0.0165)
Export	0.0429*	0.0359	0.0516**	0.0423*	0.0351	0.0509**
	(0.0244)	(0.0245)	(0.0229)	(0.0244)	(0.0245)	(0.0229)
N	3825	3825	3821	3825	3825	3821

Robust standard errors in parentheses, constant, regional and sector dummies included

* $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

cooperation with research organizations. This is in line with much of the literature on cooperation: universities and public and private research organizations can be providers of specialized knowledge for firms (Tether and Tajar 2008a), especially if the firm lacks the internal capacity to fill its knowledge gaps.

This finding is strengthened by the second triplet of specifications, which include the interaction dummies and account for likely interdependencies among the different barriers. Models 4–6 show that knowledge barriers are as important as financial barriers for driving cooperation.

An interesting result is that obstacles related to market structure and stagnating demand seem not to matter for cooperation strategies. Facing an incumbent dominated market is not associated with coping by establishing cooperation agreements. The lack of significance of the coefficient of market barriers seems to dominate most of the interaction dummies, confirming that market structure is not a strong driver of cooperation. It is interesting that the literature on barriers shows that, in general, lack of or stagnant demand are relevant factors affecting innovation investments (Pellegrino and Savona 2013; Garcia-Quevedo et al. 2014); however, at least in the French case, it seems that neither is associated with cooperation behaviour. It might be—although we are not able to test this

here—that market barriers are mainly deterrent rather than revealed, so that firms experiencing lack of demand or a competitive market structure do not initially engage in innovation activities.

One of the most consistent results of models 4–6 is that when firms face both cost and knowledge barriers, the propensity to engage in cooperation decreases. This suggests that among firms faced with the need to cope with different types of obstacles, cooperation is not the preferred strategy since it could imply a trade-off in terms of the resources needed to manage the cooperation. The benefits of cooperation rely on a certain (benchmark?) level of absorptive capacity, especially cooperation with research organizations, and the transaction costs linked to gathering information, selecting partners and establishing the cooperation. All of these aspects might represent a trade-off in terms of resources, which might deter firms from engaging in cooperation. In other words, there seems to be a sort of "cap" on the convenience of cooperating as a coping strategy if the problems to be dealt with are too many or are too diverse. When we look at the interaction term of knowledge and market barriers, it seems that firms operating in difficult markets are discouraged from cooperating with research organizations. Therefore, it seems that outsourcing knowledge to private or public research organisations is more "costly" if the firm is operating in an overly competitive or a stagnant market.

We extend our discussion of these results in the context of the complementarity test below.

3.2 Complementarity test

The complementarity test qualifies the results emerging from the baseline probit, especially models 4–6, which include the interaction terms, by uncovering their complementary or substitution effect. We gathered a great deal of information on whether firms facing combinations of several barriers (financial and lack of knowledge; financial and market structure; lack of knowledge and market structure) tend to revert to cooperation more, and tend to choose a particular set of partners.

In general, we expect the negative (positive) signs of the interaction dummies to be confirmed by a sub-modularity (super-modularity) effect when the Wald tests are applied. In addition, as mentioned above, the tests help to highlight results that were not statistically significant in the baseline probit estimations. A negative (positive) although not significant interaction, might be hiding the presence of substitutability (complementarity) between two barriers. The 'global' effect captured by the interaction term does not reveal the presence or not of complementarity or substitutability effects.

The results of the complementarity tests are reported in Table 6. The tests show no evidence of complementarity (super-modularity). Instead, we find evidence of substitutability (sub-modularity) between two couples of barriers—Cost/Knowledge and Market/Knowledge—which confirms and qualifies the results of the baseline probit. The substitutability is not sensitive to the control for the third barrier, which is alternately set to 1, 0, and to its average, in the calculation of the marginal effects on which the tests are conducted. As a further robustness check, we excluded the third barrier from each specification, but the results do not change.

The presence of substitutability in the pairs Cost/Knowledge and Market/Knowledge, strictly speaking, means that the increases in the propensity to cooperate, as a result of perceiving one or the other barrier in each pair as relevant, are larger than the increase in the propensity to cooperate induced by a switch from the case of absence of relevant barriers to the case in which both of the barriers in each pair are perceived as relevant. In

Table 6 Super- and sub-modularity of the effect of barriers' perception on cooperation

		COOP		COOPFIRM		COOPORG	
		Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)	Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)	Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)
1st barrier versus 2nd barrier (3rd barrier set to 1)							
COST	MKT	0.51 (0.23)	<0	0.25 (0.31)	<0	0.14 (0.35)	<0
COST	KNOW	12.42*** (0.00)	<0	9.74*** (0.00)	<0	15.15*** (0.00)	<0
KNOW	MKT	3.06* (0.04)	<0	3.87** (0.02)	<0	7.18*** (0.00)	<0
1st barrier versus 2nd barrier (3rd barrier set to 0)							
COST	MKT	0.51 (0.23)	<0	0.25 (0.31)	<0	0.14 (0.35)	<0
COST	KNOW	12.43*** (0.00)	<0	9.75*** (0.00)	<0	15.49*** (0.00)	<0
KNOW	MKT	3.06* (0.04)	<0	3.87** (0.02)	<0	7.22*** (0.00)	<0
1st barrier versus 2nd barrier (3rd barrier set to average)							
COST	MKT	0.51 (0.23)	<0	0.25 (0.31)	<0	0.14 (0.35)	<0
COST	KNOW	12.42*** (0.00)	<0	9.75*** (0.00)	<0	15.45*** (0.00)	<0
KNOW	MKT	3.06* (0.04)	<0	3.87** (0.02)	<0	7.21*** (0.00)	<0
1st barrier versus 2nd barrier (3rd barrier excluded)							
COST	MKT	0.44 (0.25)	<0	0.22 (0.32)	<0	0.10 (0.37)	<0

Table 6 continued

		COOP		COOPFIRM		COOPORG	
		Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)	Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)	Wald test[a] (Adj. *p* value for: H_0: coeff. 11 + 00 > = coeff.10 + 01)[b]	Sign of the linear combination (b1 + b4) + (−b2 − b3)
COST	KNOW	12.12*** (0.00)	<0	9.46*** (0.00)	<0	15.23*** (0.00)	<0
KNOW	MKT	2.95* (0.04)	<0	3.75* (0.05)	<0	7.10*** (0.00)	<0

Tests conducted on marginal effects

[a] Since we are testing one linear restriction at a time the χ^2 distribution has 1 degree of freedom as the number of the linear restrictions; H0: b1 + b4 − b2 − b3 = 0; Critical values of χ^2 (1) distribution: 6.63, 3.84 and 2.71 (***1%, **5% and *10% level of significance respectively)

[b] Adjusted *p* value for inequality tests when the Wald χ^2 statistics has 1 degree of freedom

(b1 + b4) + (−b2 − b3) ≥ 0 is index of supermodularity

(b1 + b4) + (−b2 − b3) < 0 is index of submodularity

other words, the convenience for firms to cooperate when perceiving cost/knowledge or market/knowledge barriers as jointly relevant, seems to be "sub-optimal". Thus, firms might resort to strategies other than cooperation to overcome the obstacles to innovation if these barriers are perceived as jointly relevant.

3.3 Summary of results

Overall, the probability to cooperate is influenced by the perception of relevant barriers. Indeed, the propensity to cooperate emerges as positively related to the presence of single barriers, which 'induces' cooperation more than does the joint, complementary presence of three pairs of barriers. This emerges from both the probit estimates and the complementarity tests which focus on pairs of barriers (still controlling for the third barrier not included in the test).

When we focus on patterns of cooperation with research organizations, the results point to a tendency to engage in cooperation with knowledge providers, mostly if the main problem is lack of appropriate information and human capital. Whenever this barrier is perceived in conjunction with others, the effect is sub-modular, that is, other issues become involved and the firm tends either to diminish its propensity to revert to cooperation with a research organization or to not cooperate at all.

The effects of the control variables on cooperation generally are in line with the literature. Receiving public funds to carry out R&D, persistence in R&D investments, exporting to foreign markets, belonging to a group, being a TNC's affiliate and size are all associated with higher levels of cooperation. These results are largely robust across all specifications.

4 Concluding remarks

This paper contributes to the innovation literature by questioning and empirically testing whether experiencing barriers to innovation is associated with engagement by firms in cooperation for innovation in general, and with specific partners, as a coping strategy. In doing so, the paper bridges two streams of literature which so far have been separate: an established strand of work on innovation cooperation and a more recent stream on the barriers to innovation.

We briefly reviewed the relevant contributions in both areas. Innovation cooperation has been studied from several theoretical perspectives, from industrial organization to management, including scholarship on absorptive capacity. All generally identify firms' incentives to cooperate, ranging from knowledge internalization (Arvanitis 2012), learning in complex environments (Caloghirou et al. 2003) and gaining benefit from absorptive capacity (Franco et al. 2014), to risk and cost-sharing strategies (de Faria et al. (2010). A large number of contributions within these theoretical perspectives focus on cooperation in R&D projects and touch on the issue of appropriability. This is particularly important for explaining the determinants of and constraints to cooperation with different actors, both research organizations and private firms, along the value chain, and on activities not necessarily limited to R&D projects (de Faria et al. 2010; Barge-Gil 2010).

We have argued that the large number of contributions on the determinants of (R&D and non-R&D related) innovation cooperation rarely consider the minimization of losses,

reducing the risk of failure and coping with the obstacles to innovation, as incentives to cooperate.

Firms might need to outsource knowledge or share costs and risks linked not only to basic research but also to the implementation and launch of an innovation, for instance, in a market dominated by an incumbent or where the adoption and diffusion of innovation is uncertain. A paper by Laursen and Salter (2014) analyses empirically the "paradox of openness", that is, how firms manage the opposing incentives of the search for external knowledge and maximization of appropriability. They find a concave relationship between the breadth of external search and formal collaboration for innovation, and the strength of the appropriability strategy. Cooperation might be costly, impose a too-high trade-off in terms of the resources needed to manage it or of appropriability, and it can be subject to failure (Lhuillery and Pfister 2009).

In this context, this paper addressed the important issue of disentangling whether cooperation activities with different partners are the result of a coping strategy to which the firm resorts when faced with one or more barriers to innovation, or a particular combination of these barriers.

It is important to bear in mind that what we infer from our empirical analysis is based on statistical association rather than on causal effects. Our analysis is a cross-sectoral estimation of the probability to engage in cooperation as a function of perception of one or three combinations of pairs of obstacles, and several control variables. We have provided a complementarity test of the super- or sub-modular effect on cooperation of a status shift from absence of barriers to perception of one or two barriers to innovation in several combinations (cost/knowledge; cost/market; knowledge/market) of barriers.

Results show that facing barriers generally is associated with the adoption of cooperation strategies, and particularly in the case of financial barriers, which are shown to be positively related to all types of cooperation. Firms resort to cooperation based on a cost-sharing strategy. Knowledge obstacles trigger cooperation with research organizations: firms collaborate with research organizations to mitigate shortages of skills and competencies.

Our results confirm also that cooperation is subject to a sort of diminishing returns effect if used as a coping strategy to mitigate the obstacles to innovation: our results provide robust support for the absence of super-modularity and the presence of substitutability effects of the joint perception of barriers. While a firm experiencing a specific obstacle is prone to "share the pain" with partners, the joint experience of several barriers does not exert a cumulative effect since there is no intensification of cooperation.

The sub-modularity effect is especially evident in the case of the joint presence of cost or market obstacles with knowledge-related barriers: lack of adequate information on technologies or of appropriate skills seem to be the problems which, when experienced jointly with other types of bottlenecks, lead firms to increase cooperation less than in perception of a single barrier as relevant.

Overall, we would argue that prior lack of absorptive capacity in firms tends to exacerbate the perception of barriers of different types, e.g., cost-related barriers, cause firms to reduce their reliance on external partners in the joint presence of various types of obstacles. Our paper adds to the literature on absorptive capacity, with the aim of including the role of the barriers to innovation as potential drivers of cooperation depending on a minimum level of absorptive capacity in the firm.

Our findings have implications for policy if the priority is to enhance cooperation among firms, and with research organizations and especially, from the perspective of a strategy to cope with the obstacles to innovation.

More generally, borrowing from a systems failure (rather than a market failure) framework for innovation policy (e.g. Metcalfe 2005; Woolthuis et al. 2005), we would argue that the presence and effect of financial and non-financial obstacles to innovation equate to many of the several dimensions of systemic failures. *Soft institutional failure* might encompass lack of an adequate financial system for firms to access not excessively costly funds for innovation investments. *Capability failures* refer to the consequences of skills and knowledge shortages that firms might experience when engaging in innovation. Of most interest is that the framework refers to *interaction failures,* which encompass a wide variety of inter-firm connection failures including strong and weak network failures, lack of weak ties and myopia due to internal orientation (Woolthuis et al. 2005).

Our evidence suggests that cooperation for innovation is intensified as a result of a range of systemic failures and, therefore, emerges as a coping strategy in the presence of relevant barriers. This result should help policy makers to address systemic failures by selectively supporting cooperation and deal with what Woolthuis et al. (2005) refer to as *interaction failures.* This perspective supports the view proposed by others (Coad et al. 2016), that policy intervention to reduce barriers (e.g., by supporting and facilitating risk and cost-reducing cooperation) should not be ascribed to *market failure fixing,* but rather to a selective, deliberate and systematic intervention to address systemic failure. In this respect, we hope that further research will investigate more directly the real effectiveness of system-oriented policies to mitigate the barriers to innovation for firms.

More generally, more research is needed to disentangle the relation between innovation barriers and cooperation strategies. In this context, the availability of panel data could lead to better analysis of the causal framework and feedback mechanisms between obstacles and collaboration. An additional point concerns the availability of data on cooperation and barriers. Our dataset does not provide fine-grained information to capture the intensity of obstacles (e.g., in a continuous way) and collaboration (e.g., resources committed) or the number of different collaborations with a specific type of partner (e.g., the number of different suppliers with which the firm cooperates). We hope that future research will capture these aspects.

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