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ORGANIZING FOR INNOVATION:
R&D PROJECTS, ACTIVITIES AND PARTNERS

Bruno Cassiman*
Chiara Di Guardo**
Giovanni Valentini***

* Professor of General Management, IESE
** Professor, University of Cagliari
*** Doctoral Candidate, IESE

IESE Business School – University of Navarra
Av. Pearson, 21 – 08034 Barcelona, Spain. Tel.: (+34) 93 253 42 00 Fax: (+34) 93 253 43 43
Camino del Cerro del Águila, 3 (Ctra. de Castilla, km 5,180) – 28023 Madrid, Spain. Tel.: (+34) 91 357 08 09 Fax: (+34) 91 357 29 13

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Abstract

We explore how R&D project characteristics condition the governance of an R&D project and its individual activities. Prior literature has tried to understand the factors – both at the industry and at the firm level – that influence the way in which firms partner for innovation. In this paper, through the analysis of detailed data from a subsidiary of STMicroelectronics, we identify the main drivers of partner selection for innovation. Partnering or contracting with universities for innovation is common practice for developing new – original – knowledge, as opposed to applying existing knowledge to a problem. But firms are more reluctant to partner, especially with other firms, when that knowledge directly enhances their competitiveness. However, conditional on cooperation, partners are more likely to act individually when the project is strategically important. Contracting for innovation to universities or research centers, as opposed to partnering, happens for more experimental projects, where highly original knowledge is developed, and typically early on in the project.

Keywords: Innovation strategy, Technological innovation, R&D projects' organization, Partner selection

ORGANIZING FOR INNOVATION:
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Introduction

The boundaries of innovation are shifting. Historically, firms organized R&D internally and relied on outside contract research only for relatively simple functions or products (Mowery, 1983; Nelson, 1990). However, more recently, there has been a general growth in corporate partnering and reliance on various forms of collaboration and external sourcing in R&D (Chesbrough, 2003; Granstrand, Bohlin, Oskarsson, & Sjoberg, 1992; Powell, Koput, & Smith-Doerr, 1996; Rigby & Zook, 2002). The potential benefits of external sourcing include access to complementary technological resources, faster development of innovations, and improved market access (Hagedoorn, 1993). And while, in the past, internal and external sourcing were approached as substitutes, they now are seen as complements (Cassiman and Veugelers, 2003). Arora and Gambardella (1990) argue that even the possible different strategies to get external linkages in R&D (agreements with other firms, research agreements with universities, investments in the capital stock of new firms, and acquisition of small firms) are complementary, and that each strategy enables the firm to gain access to a specific benefit.

To gain insight into corporate behavior, researchers have analyzed different sets of variables driving the organization and sourcing strategies of firms' R&D. One group of studies focuses on industry characteristics. Pisano (1990) and Beneito (2003) argue that in-house organization of R&D activities is more likely the more competitive the environment in which firms evolve. Bayona, Garcia-Marco, and Huerta (2001) and Miotti and Sachwald (2003), among others, provide evidence that firms in more technology-intensive sectors have a greater propensity to establish cooperative R&D agreements. Sakakibara (2001) also points out that firms in R&D-intensive industries conduct cooperative R&D projects in order to enter new R&D-intensive industries. Nagarajan and Mitchell (1998) indicate industry "technological regime" as the main driving factor, and then argue that equity alliances are used in regimes of encompassing technological change, internal R&D dominates when technological change is incremental, and non-equity alliances are prevalent during periods of complementary technological change (i.e., radical changes that have a greater effect on the firm's complementary activities than on its core resources/capabilities). Building on these results, Nicholss-Nixon and Woo (2003) analyze how technology sourcing practices vary within regimes of technological change and how this variation is related to the ability to generate new technical output. Powell et al. (1996) show that when there is a regime of rapid technological development, research breakthroughs are so broadly distributed that no single firm has all the internal capabilities and knowledge needed for success. In such an environment, the locus of innovation is found in a network of inter-organizational relationships.

A second group of studies considers firms' characteristics as the main driver of R&D strategy. Firms' age is a relevant predictor. Young firms are in fact likely to be most affected by key external relationships (Eisenhardt & Schoonhoven, 1996), mainly because they are resource constrained (McDougall, Shane, & Oviatt, 1994), and because they strongly depend upon knowledge rejuvenation to survive and grow (Autio, Sapienza, & Almeida, 2000). The possible role of size, although highly correlated with age, is more controversial. Large firms are expected to have a higher "absorptive capacity" (Cohen & Levinthal, 1990), but also are endowed with the necessary technical and financial resources to carry out primarily own R&D. This dilemma is not unanimously resolved in empirical studies: Hagedoorn and Schankeraad (1994) and Colombo and Garrone (1998) find a positive relationship between firms' size and cooperation in R&D, whereas Robertson and Gatignon (1998), inter alia, do not encounter this correlation. Finally, past choices and sourcing history are thought to increase organizational inertia and thus be likely to guide future decisions along the historical paths (Steensma & Fairbank, 1999).

A third group of studies addresses the interaction between firms and their environment, contending that corporate behavior is influenced by the positions held by organizations in a broader, market-related context. Stuart (1998), for instance, argues that firms in technologically "crowded" positions and with high prestige form technological alliances at a higher rate.

Yet, while prior literature has deeply scrutinized which factors at the industry and at the firm level have an impact on the organization of firms' R&D activities, little attention has been devoted to the significance of the specific attributes of the R&D activities themselves. In particular, if we consider that the great majority of R&D activity is carried out and organized through *projects*, it is immediately evident how important it is to understand which R&D project attributes influence project organization and how. Based on detailed study of the R&D projects of a subsidiary of STMicroelectronics, the world's fourth largest producer of microelectronic components, our paper tackles this issue with an unprecedented richness of data.

In this paper, we will attempt to show that the form of governance of R&D projects depends on the projects' knowledge attributes, and that while external partners may be more productive in developing new knowledge, recourse to external sourcing is limited when valuable, strategic knowledge may be exposed. We will also argue that universities and firms are sought as partners for different tasks and intervene in different phases of R&D projects.

The paper is organized as follows. First, we review the related literature and discuss how R&D project characteristics may influence project boundaries. After describing the empirical setting of the study, we present the results of our analyses. A discussion section concludes.

Related literature: Main insights and limitations

Not all R&D projects are alike. Accordingly, we should expect their governance forms to differ. Nonetheless, we know surprisingly little on this matter. Which project characteristics have an influence on their organizational design? How does project organization vary across these characteristics? Two streams of literature may guide our search for an answer to these questions. First, the literature on technology sourcing; and second, prior studies on R&D

project organization. We analyze them in turn, highlighting also why these studies fail to provide a conclusive answer to the questions we pose.

Technology sourcing decisions are amongst the most important choices management faces in today's globally competitive environment. Typically, firms may have to decide whether to develop a specific technology internally, in cooperation, or whether to acquire it through licensing or acquisitions (Steensma & Fairbank, 1999). Schilling and Steensma (2002) suggest that technology's uniqueness, risk of imitability and commercial uncertainty should favor internal solutions. Robertson and Gatignon (1998) argue that alliances will be preferred over internal development when technological uncertainty increases. Conversely, internal development is favored over alliances as asset specificity and measurement problems increase. Finally, Delmas (1999) adds that tacit, complex, and strategic technologies are more likely to be developed through alliances than acquired through contracts. He also highlights how, in environments where know-how is the key asset, building specific assets, rather than protecting them, may be the main issue. However, what applies to particular technologies is not necessarily valid for R&D projects. Technology sourcing refers to a given, definite set of knowledge and objectives. R&D projects differ in the degree of uncertainty involved, broadness of applicability, risk, and distance from market application (Hauser, 1998). Technology sourcing is about meeting present technological needs, whereas R&D is about building future scenarios (Rosenberg, 1990).

Though the literature on technology sourcing is somewhat developed, R&D projects are very rarely adopted as the unit of analysis of empirical studies. Pisano (1990) and Ulset (1996) constitute two notable exceptions. Pisano (1990) argues that two relevant circumstances that influence pharmaceutical companies in their decisions regarding procurement of biotech R&D are small-numbers bargaining problems and appropriability issues. The first one indicates that when a company contracts out R&D capabilities to a small group of potential suppliers, the likely necessary investments in co-specialized assets may increase the chances of opportunistic behavior of suppliers, thus making renegotiation or partner switching more difficult in the future. In that case, internal development should be preferred. The second circumstance highlights that the inability to properly define or enforce intellectual property rights creates a hazard of expropriation of the knowledge generated through investing in R&D, particularly if contracted out. This hazard is expected to increase with market competition, and thus greater competition should lead to internalization of the R&D effort. Ulset (1996) reaches similar conclusions and maintains that the benefits of R&D outsourcing in terms of quicker access to more advanced technology can seldom be achieved without additional transaction costs. Nonetheless, such costs can either be managed or avoided by strengthening administrative control rights and switching to vertical integration as a last resort.

These two studies encapsulate the stylized facts that prior research on R&D projects has produced, but also highlight its limitations. First, earlier literature on R&D projects has seldom analyzed hybrid forms of governance, e.g. cooperation, as an alternative to contracting. Second, it has often reasoned as if projects should be either fully developed internally or fully contracted out, ignoring the frequent case in which only part of a project is developed through external sourcing. Third, the role that different external actors (universities, firms, research centers, etc.) may play in project organization is hardly ever highlighted. In other words, studies have tended to analyze whether or not a given project is likely to be contracted out, but not to whom or whether there are any relevant differences among possible contractors that may explain the chosen form of governance. Finally, and perhaps most importantly given our objectives, the analysis is generally based on firm or industry features, rather than on attributes of the projects themselves. Furthermore, while prior literature has used transaction costs and the risk of opportunistic behavior as the dominant factors explaining the form of governance of R&D projects, other contributions underline that these cannot fully account for such a tremendously complex phenomenon as organizational boundaries (Holmstrom & Roberts, 1998; Madhok, 1997; Madhok, 2002; Silverman, 1999). Transaction costs economics assumes that, due to economies of specialization and the administrative and incentive limits of hierarchies, markets are a more efficient structure, unless transactions are surrounded by special circumstances that increase transaction costs (Williamson 1975; 1985). However, this paradigm fails to highlight that firms differ in their resources, and that it takes time for organizations to create and enhance capabilities through experience, learning, and investment.[1] As Coase (1988; 1990) himself has highlighted, it is also necessary to consider that firms have different production costs for different activities, and that these are largely determined by the other activities that the firms have undertaken. Organizational boundaries are thus responsive to more than hold-up problems (Holmstrom & Roberts, 1998; Conner & Prahalad, 1996).

R&D project characteristics and organization

Different types of organizational forms may be adopted in R&D projects, each having specific advantages and drawbacks. Related literature seems to suggest that the use of external agreements is favored to quickly access fresh knowledge and exploit complementary capabilities. But the achievable benefits may be offset by the risk of inappropriability, leakage, and opportunistic behavior. The organization of R&D projects should thus depend on the alignment between project characteristics, organizational form, and the capabilities portfolio of the firm itself and potential partners (Madhok, 2002).

In this paper, we will assume that three main organizational forms may be adopted: internal development, contracting, and cooperation (Williamson, 1991). Moreover, two main broad potential partners may be identified: business firms and universities / research centers. These clearly vary in their capabilities, organizational goals, and incentives (Dasgupta & David, 1994). This section discusses which R&D project attributes are relevant in determining the form of project governance and discusses how those attributes may relate to different organizational forms and different partners.

The new competitive landscape forces organizations to actively acquire knowledge, since a firm's competitive advantage is now more dependent on continuous knowledge development and enhancement. Therefore, knowledge has become a central theme in strategic management (Grant, 1996; Spender, 1996). Along these lines, we contend that the knowledge characteristics of R&D projects are fundamental variables to explain governance decisions. While knowledge has been defined in a variety of ways (e.g. Hedlund, 1994; Nonaka & Takeuchi, 1995; Spender, 1996), it has been shown to be an important contingent variable influencing organizational design in different technological settings (Birkinshaw, Nobel, & Ridderstrale, 2002; Zander & Kogut, 1995). R&D generates new knowledge and helps assimilating existing knowledge (Cohen & Levinthal, 1990). And firms' R&D strategy depends on the characteristics of the productive knowledge on which it is based and the means that are effective in protecting knowledge assets (Winter, 1997). But if the fact that R&D and knowledge are intrinsically linked is widely recognized, much less – if anything – is known about how the knowledge involved in R&D projects could or should influence their organization.

[1] While stating that the mode of organization depends on the sum of both production costs and transaction costs, Williamson treats production in a somewhat "stylized" manner, holding production technology constant and exogenously determined (i.e., equally available to all firms). Differences in production costs are allowed in Williamson's (1985) approach, but these can be primarily described in terms of economies of scale and generic vs. specialized technologies.

Four important dimensions of the knowledge involved in R&D projects may affect project organization. A first relevant dimension of a project's knowledge is its basicness, i.e. its relatedness to fundamental research (Rosenberg, 1990). On the one hand, the basicness of a project should favor external sourcing. Since the seminal papers by Arrow (1962) and Nelson (1959), it has been recognized that firms may have little economic incentive to invest in basic research. Uncertainty about the results and appropriability hazards are two relevant reasons for such lack of incentive. These same factors may also drive the failure of the market for knowledge. Cooperation in R&D may decrease the intensity of these obstacles. Firstly, by cooperating with other economic subjects firms may share risks and costs (Arora & Gambardella, 1990; Miotti & Sachwald, 2003). And secondly, cooperation may facilitate the internalization of knowledge spillovers (D'Aspremont & Jacquemin, 1988). Moreover, by way of cooperation firms may learn and build capabilities they would not get by simply contracting out their needs (Hagedoorn & Schakenraad, 1994). Universities and research centers should be better able to leverage their capabilities in basic research, given that their efforts are traditionally oriented towards it, and should therefore be a preferred partner (Dasgupta & David, 1994; Graff, Heimann, & Zilberman, 2002). A large literature suggests that universities and industrial firms have complementary resources and skills. For example, while universities have access to intellectual resources and a world-class basic research infrastructure, industrial firms usually have practical expertise, financial resources, internship opportunities for students, and employment opportunities for graduates and students (Santoro & Gopalakrishnan, 2000).

The novelty of a project's knowledge relative to the firm's existing knowledge base is a second important dimension (Abernathy & Clark, 1985). Novelty increases the propensity to open the boundaries of the project. Firms are more likely to look for complementary external resources when they are moving away from their knowledge domain (Sakakibara, 2001), looking for partners with more productive resources given a specific task (Kogut & Zander, 1992). However, this could be true only up to a certain point. Received theory argues that when melting different knowledge bases, some knowledge relatedness is needed in order to benefit from absorptive capacity (Cohen & Levinthal, 1990), but also that if knowledge bases are too similar or too different, then there is no room for valuable external contributions to innovation (Ahuja & Katila, 2001).

However, the higher the basicness and the novelty of a project, the higher its uncertainty. Therefore, internal development could provide a better means to respond to unanticipated contingencies (or opportunities) over the course of the project (Oxley, 1997). While technically novel projects need creative problem solving, they may also cause unwanted delays and cost overruns (i.e. increase outcome uncertainty): hierarchical governance may be needed to guard against these hazards (Ulset, 1996). Also, internal development relieves firms from fully specifying contractual arrangements, whose terms are less obvious and known when information is new and uncertain (Williamson, 1991). In addition, the more basic and novel the project, the lower the ability to assess its outcomes. Uncertainty on performance measurement creates a higher incentive for opportunistic behavior of partners, and thus should make internal development more likely (Robertson & Gatignon, 1998).

Contractual hazards and the incentive for the external actors involved in an R&D project to behave opportunistically are higher when the expected pay-off of such behavior is higher. The expected pay-off depends both on (a) the intrinsic potential value of the results of the project, and (b) the probability of being able to capture the value itself. These, in turn, depend on two important project knowledge dimensions: strategic importance and codifiability. Projects whose knowledge is of relevant strategic value may increase the incentive for partners to cheat and perhaps engage in a "learning race" and avoid sharing the developed knowledge (Hamel, 1991). It is more likely to be so when the external actor involved is a firm, as opposed to a university or research institute (Bonaccorsi & Piccaluga, 1994; Goldfarb & Henrekson, 2003). In addition, projects of strategic importance more often imply commitments and specific investments (Ghemawat, 1991). The more specialized a resource, the lower its value in alternative uses, and the higher the probability of being held up by a partner. Therefore, internal development should be preferred (Robertson & Gatignon, 1998; Williamson, 1985). Nonetheless, it is in highly strategic projects that it becomes evident how no single firm has all the capabilities necessary for success (Powell, 1990). As firms may lack competence in a number of technological fields, cooperation with other enterprises creates the necessary complementary inputs and makes it possible to capitalize on economies of scope (Delmas, 1999).

Finally, the extent to which the knowledge of a project is codifiable, as opposed to tacit, is the fourth relevant knowledge dimension (Winter, 1997). The sources and significance for organizations of this dimension of knowledge are explored in depth in Nelson and Winter (1982). When a project's knowledge is prevalently codified, it is easier to "steal" project outcomes and a partner's competencies (Nelson & Winter, 1982; Zander & Kogut, 1995), thus making opportunistic behavior more probable (and consequently development through alliances less probable). However, Arrow (1974) contends that a key advantage of organizations is their ability to economize in communication through a common code. When the knowledge to be shared is tacit, the cost of communicating and coordinating with an external partner are higher, and so internal organization is presumed to be more efficient (Kogut & Zander, 1992).

Methods

Research Setting

In the quest for new and more insightful empirical evidence on the theory of organizations, Williamson (1991b) concedes there is merit in shifting the emphasis away from the best generic institutional form for organizing a particular transaction, to the best way for a specific firm to organize that transaction. Accordingly, our study is based on the case of a subsidiary of STMicroelectronics (ST). ST is a global company based in Geneva and the fourth largest producer of microelectronic components in the world, according to the ranking published by Gartner Dataquest (2003). The group currently has more than 45,000 employees, 16 advanced R&D units, 17 main manufacturing sites, and 88 sales offices in 31 countries. Our analysis focuses on an ST subsidiary which distinguishes itself worldwide for its research focus and the large amount of resources allocated to R&D, whose location we cannot reveal for confidentiality reasons.

This represents an especially attractive setting to study innovation strategy and the governance of R&D projects. First, the semiconductor industry is a fast-moving, high-tech industry where R&D plays a fundamental role in competition. The impulse toward technological innovation given by nanotechnology and the opening of new application fields, together with the global dimensions of the market and competitors, make this sector highly dynamic and competitive. And second, a key contribution to ST's success has been its "open" innovation process. This includes strategic alliances with key customers, technology development alliances with both customers and competitors, development alliances with major equipment, materials and CAD suppliers, and partnerships with multinational R&D organizations, universities, and research institutes.

Data and Measurement Issues

Data were collected both from primary and secondary sources. After having reviewed a variety of public documents concerning ST's innovation strategy, in order to better understand ST's internal innovation process we interviewed three R&D division directors, a project manager, and the head of the department for external R&D contracts. We also interviewed the persons in charge of two of ST's most frequent "science" research partners. Interviews lasted between 45 and 60 minutes each, and were recorded. They were conducted in 2002, and all the authors attended them.

With the help of industry experts, we then collected fine-grained data at the project level, developing a database that contains 52 R&D projects that got started between 1998 and 2002. More specifically, our sample comprises all the R&D projects for which ST has sought some form of external financing in this time-frame. Not only did we collect data at the project level, but we were also able to explore the structure of the project. Each project is in fact composed of a number of single activities, which generally get started sequentially. For each activity, besides other technical information (what the activity is technically aimed at) and organizational information (the subject in charge of it), we know whether the activity at stake is intended to develop and acquire new knowledge, as opposed to applying and obtaining concrete results from knowledge previously developed or acquired. All the available information concerning the project is reported in the application for external financing.

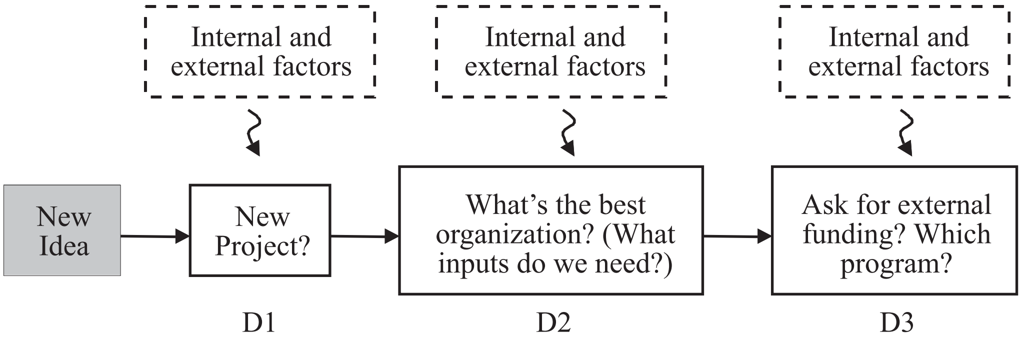
Each project for which external funding is sought is evaluated and characterized by the applicants with respect to its knowledge content. First, on a 1-to-3 scale, the novelty and originality of the knowledge developed in the project as compared to the firm's technological domain is evaluated. Second, again on a 1-to-3 scale, the relevance of the knowledge developed to achieve product or process innovations that can enhance the firm's competitiveness is assessed. This measure clearly relates to the strategic value of the project. And third, on a 1-to-4 scale, the ease of industrialization and transferability to manufacturing of the project outcomes are evaluated. This measure can be used as a proxy for the relative codification of the project's knowledge (Grant & Gregory, 1997). Finally, we constructed a measure using the percentage of project activities aimed at developing new knowledge (as opposed to applying it), which can serve as an indicator of the basicness of the project.

Measuring intangible variables is arguably the main difficulty in empirical research on transaction costs as well as in the capabilities approach (Klein & Shelanski, 1995). While our measures may contain a certain degree of subjectivity, they are still reasonably valid. First, the application for external public financing for industrial R&D projects is a complex process. All of our interviewees – whether belonging to ST or public research institutes – consistently acknowledged this. The process requires a deep technical knowledge as well as a sound understanding of the regulatory context. All the applications must contain some basic project characteristics, some quantitative, some qualitative. And all the applications are reviewed by independent experts nominated by the funding organization in a competitive process in which several applicants are denied financing. Misrepresenting the characteristics of the project is easily detected by the reviewers, with the consequence of drastically decreasing the chances of being financed and harming the firm's reputation. Second, financing applications – and thus knowledge attribute evaluations – have been compiled by the same team of experts over the four years under scrutiny. The team is not involved directly in the decision regarding project organization. These circumstances, the cross-check of measures of highly qualified observers made for entirely different purposes than those of our study, increase the validity of the measures at stake (King, Keohane, & Verba, 1994).

Lastly, two additional important issues are to be stressed. First, the subsidiary under scrutiny generally seeks external financing for the great majority of its research projects, ruling out – or at least significantly reducing – one possible source of selection bias. Second, the request for external financial support does not alter the organization of the projects. Our interviews highlight the fact that the optimal organizational form is decided ex ante. And then, and only then, does the search for the most appropriate financing program begin, depending on project characteristics and organization.[2] What really matters is which funding program to apply to, *given* the project's features. Thus, no systematic bias affects our measures. Figure 1 reports the sequence of decisions ST adopts. Our empirical analysis refers to decision D2 and is based on the projects for which decision D3 has been affirmative.

One last indicator of a project's knowledge characteristics may be its total budget (or cost). Projects with larger research budgets are thought to involve research of a broader scope than other projects, as opposed to researching a narrow project in greater detail (see Hall, Link, & Scott (2003) for such an argument).

Figure 1. R&D projects decision sequence



Results

The projects included in our sample have an average length of 31.5 months and, on average, take 8.2 man-years to complete. Seven different strategic lines of innovation may be explored: technological and design platforms; advanced applications, new devices, and optoelectronic integrated circuits; memories and system on chip; nanotechnologies; new materials; bioelectronics, health; new computational models. The ideas for the projects may have originated externally (in a university or in a firm) or internally (in the same R&D division in which the projects are carried out, in another R&D division, at the subsidiary's central R&D unit, or at the corporate R&D unit). Projects may also have different clients, internal and/or external. An analysis of the correlation matrix between the projects' origin and clients (which is not reported here, but is available upon request from the authors) highlights the following results. First, the only "originator" that has a strong correlation with the fact of being also a client of the same project is central R&D (r = 0.70). Second, projects that originate from universities are positively correlated to having corporate R&D as their client (r = 0.40). This is consistent with the stylized fact that corporate R&D is generally closer to science (Hauser, 1998). Third, projects that originated in the same R&D division where they are carried out are negatively correlated to having a customer external to the firm (r = –0.51). Units' autonomous projects seem thus to be scarcely market oriented. And four, as expectable, projects that originated outside ST are positively correlated to having external clients (r = 0.53). 90% of the projects span the boundaries of ST, having at least one partner or

[2] There are three broad sources of external financing.

a contractor, and 29% have both. Table 1 reports aggregated data regarding partners and contractors. On average, ST sustains 73% of the costs and provides 74% of the researchers.

Table 1. Descriptive data on R&D projects' form of governance

Percentage of projects in which there is…

Partnership with universities (total)	37%
Partnership with universities (conditional on having a partner)	59%
Partnership with a research center (total)	21%
Partnership with a research center (conditional on having a partner)	34%
Partnership with another firm (total)	42%
Partnership with another firm (conditional on having a partner)	69%
Contracting with universities (total)	40%
Contracting with universities (conditional on having a contract)	70%
Contracting with a research center (total)	31%
Contracting with a research center (conditional on having a contract)	53%
Contracting with another firm (total)	8%
Contracting with another firm (conditional on having a contract)	13%

Given the small number of observations and without loss of generality, in the following analyses we will group together cooperation with universities and research centers. Descriptive statistics and correlations of relevant variables at the project level are reported in Table 2. It appears that the dummies indicating cooperation are positively correlated with the basicness and the ease of industrialization. Conversely, these dummies are negatively correlated with the projects' market and competitiveness relevance. Projects carried out in partnership with a university are positively correlated with the novelty of project knowledge, whereas the reverse is true for projects carried out with a firm. These results are confirmed if we observe the difference in means of projects' knowledge attributes depending on their governance form, which are reported in Table 3.

When projects are primarily directed to knowledge creation as opposed to exploitation (i.e. more basic), more productive external resources are sought in spite of the uncertainty involved. Cooperation is preferred to contracting. By cooperating, firms may learn and develop capabilities they would not obtain by simply contracting out their needs (Hagedoorn & Schakenraad, 1994). However, when the knowledge developed or applied is particularly novel, the capabilities of the university are preferred to those of other firms, in particular through contracting. This may depend on specific skills of universities and research centers which better fit the goal of the project, as well as on a lower fear of opportunistic behavior. Novelty of knowledge in fact augments the uncertainty surrounding the project, thus making opportunistic behavior more likely. When the knowledge created does not have strategic importance for the firm, cooperation is more frequent. Finally, consistent with prior literature (Kogut & Zander, 1992), projects characterized by less codified knowledge are primarily conducted internally. Project cost does not significantly differ for projects involving other partner firms. This suggests that external resources are sought for their quality and technological complementarity, and not simply to share the risk (and the expenses) of expensive projects. When projects are characterized by contracting to universities, their cost is significantly higher. Given that projects with higher costs are thought to be undertaking research of a broader scope (Hall et al., 2003), this may reinforce the argument that universities are sought when exploring new technological areas. Yet, the counter argument that R&D contracting is the cause of higher project cost cannot be refuted.

Table 2. Descriptive statistics and correlations

		Mean	St. Dv.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Partnership with a firm (dummy)	0.42	0.50	1													
2	Partnership with university (dummy)	0.42	0.50	0.21	1												
3	Contracting with a firm (dummy)	0.08	0.27	0.04	0.19	1											
4	Contracting with university (dummy)	0.56	0.50	-0.25	-0.33	0.11	1										
5	Total project cost[a]	9.85	4.94	-0.02	-0.24	0.08	0.35	1									
6	Basicness	0.82	0.24	0.28	0.36	0.09	0.21	0.09	1								
7	Novelty	2.00	0.52	-0.08	0.15	0.14	0.44	0.11	0.53	1							
8	Strategic importance	2.29	0.70	-0.36	-0.25	0.19	0.37	0.25	0.21	0.16	1						
9	Codifiability	2.40	1.16	0.31	0.24	-0.10	0.14	-0.12	0.25	0.23	-0.41	1					
10	Origin = university	0.08	0.27	-0.10	0.19	0.46	0.26	0.10	0.19	0.28	0.09	0.09	1				
11	Origin = other firm	0.23	0.43	0.64	0.18	0.01	-0.25	0.13	0.07	-0.09	-0.36	0.20	0.01	1			
12	Financing program 1	0.65	0.48	-0.52	-0.03	0.05	0.49	0.22	-0.13	0.16	0.30	-0.03	0.21	-0.37	1		
13	Financing program 2	0.19	0.40	0.57	0.37	-0.14	-0.55	-0.20	0.17	-0.09	-0.35	0.17	-0.14	0.54	-0.67	1	
14	Financing program 3	0.15	0.36	0.07	-0.37	0.08	-0.05	-0.06	-0.01	-0.10	-0.02	-0.15	-0.12	-0.11	-0.59	-0.21	1

[a] For reasons of confidentiality, project cost has been measured on a 1-to-21 uniform scale.

Table 3. Project knowledge attributes depending on project governance form: Means and t-test for difference in means

	Dummy for cooperation in the project with a university		Dummy for cooperation in the project with a firm	
	1	0	1	0
Basicness	0.92**	0.75	0.90*	0.76
Novelty	2.10	1.93	1.95	2.03
Strategic importance	2.10†	2.43	2.00**	2.50
Codifiability	2.73†	2.17	2.82*	2.10
Cost	8.50†	10.83	9.73	9.93
	Dummy for contracting in the project with a university		**Dummy for contracting in the project with a firm**	
	1	0	1	0
Basicness	0.86	0.76	0.90	0.81
Novelty	2.21***	1.74	2.25	1.98
Strategic importance	2.52**	2.00	2.75	2.25
Codifiability	2.55	2.22	2.00	2.44
Project cost	11.38*	7.91	11.25	9.73

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

To assess these initial intuitions, we performed several other econometric analyses. As for cooperation in R&D projects, four possible outcomes are possible in our setting: no cooperation, cooperation with a firm, cooperation with universities and/or research centers, and cooperation with both a firm and university/research center. We therefore estimated a multinomial logit model with four choices. The results are presented in Table 4. The baseline case / comparison group is “no cooperation”. Two general effects are evident. First, the more basic a project, the more likely one is to observe cooperation. Second, the higher the potential value of the project in terms of market competitiveness, the less likely cooperation is to occur. This confirms the hypothesized trade-off between the search for valuable external resources when developing new knowledge and the risks of appropriability of outcomes and partners’ opportunistic behavior. The null hypothesis that the parameter estimates for strategic importance and basicness of knowledge are the same for cooperation with firms as for cooperation with universities is not rejected by the appropriate test.

Table 4. Results of multinomial logit: Determinants of cooperation.[a]

	Coop with a firm	Coop with university	Coop with both
Constant	2.68 (2.81)	1.31 (2.53)	- 9.2 (6.70)
Project cost	0.12 (0.11)	0.01 (0.10)	0.08 (0.12)
Basicness	5.85* (3.08)	4.55† (2.72)	24.25** (7.83)
Novelty	- 0.70 (1.36)	0.81 (1.10)	-2.66 (1.75)
Strategic importance	-3.57** (1.25)	-2.91** (1.17)	-3.34** (1.29)
Codifiability	0.34 (0.52)	0.08 (0.44)	0.43 (0.56)
N of observations	52		
χ^2	51.29**		

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

As a robustness check, we also estimated several logit regressions to understand what factors drive cooperation with universities / research centers and other firms separately. We start by analyzing the drivers of cooperation with universities and/or research centers. The corresponding logit results are presented in Table 5; model (1) is our base specification. Consistent with prior literature (e.g. Hall et al., 2003), the parameter estimate for the basicness of the project is positive and significant ($p < 0.05$), indicating that the more activities are dedicated to developing knowledge (as opposed to applying it), the more likely the project will be carried out in partnership with a university. Conversely, the parameter estimate of a project's strategic importance has a negative sign ($p < 0.1$). As predicted by TCE, potential project value may increase the likelihood of opportunistic behavior and therefore discourage cooperation.

However, the propensity to cooperate with universities may be merely driven by the "origin" of the project, i.e. the origin of the innovative idea that eventually led to the R&D project under scrutiny. Potentially, if the idea originated at the university itself, this could imply a higher basicness of the project as well as a higher propensity of ST to cooperate with this institution. Specification (2) includes dummy variables for the projects' origin and prior results are confirmed. Finally, the propensity to cooperate with the university may also depend on the specific strategic innovation line the project belongs to: specification (3) includes the dummies for innovation lines, and our initial results remain robust. Though our reconstruction of the decision process highlights that the request for external financing does not influence the organization of the process, we also estimated a specification that includes dummies for financing programs. The results – not reported here – are in accordance with those of our basic specification.

Table 5. Results of logit regressions: Propensity to cooperate with universities or research centers.[a]

	(1)	(2)	(3)
Constant	-1.39 (2.28)	-0.84 (2.31)	0.31 (3.52)
Project cost	-0.10 (0.07)	-0.12 (0.08)	-0.10 (0.08)
Basicness	5.53* (2.31)	5.27* (2.31)	6.33* (2.49)
Novelty	-0.17 (0.82)	-0.34 (0.88)	-0.76 (1.14)
Strategic importance	-1.00† (0.56)	-1.00† (0.65)	-1.03† (0.65)
Codifiability	0.00 (0.34)	0.00 (0.35)	-0.14 (0.41)
Origin = University		1.71 (1.36)	
Origin = Other Firm		0.46 (0.95)	
Dummies for innovation line included	No	No	Yes
N of observations	52	52	50
χ^2	16.26**	18.43**	17.60*

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

The results of the logit analyses aimed at estimating the propensity to cooperate with another firm in an R&D project are presented in Table 6. Specification (1) shows that the more basic a project, the more likely it will be carried out in cooperation with a firm ($p < 0.01$). Conversely, the parameter estimates of the novelty of knowledge and its strategic importance are negative and highly significant (respectively $p < 0.05$ and $p < 0.01$). We may infer that projects carried out in partnership with a firm are basic but fairly related to the state of the art. Again, the negative effect of the project's strategic importance may indicate the "fear" of opportunistic behavior, therefore discouraging cooperation. Results are robust to the introduction of financing program dummies, with the exception of the novelty of the knowledge, which then becomes marginally significant. Results remain also robust when introducing the dummies of the innovation lines [specification(3)].

Table 6. Results of logit regressions: Propensity to cooperate with another firm.[a]

	(1)	(2)	(3)
Constant	0.57 (2.19)	-8.84† (5.01)	-0.58 (3.78)
Project cost	0.04 (0.07)	-0.05 (0.11)	0.00 (0.08)
Basicness	7.14** (2.43)	17.79** (7.22)	8.61** (3.00)
Novelty	-2.45* (1.13)	-2.17† (1.31)	-2.13 (1.48)
Strategic importance	-1.50** (0.62)	-1.72† (1.07)	-2.41** (0.87)
Codifiability	0.42 (0.38)	0.39 (0.57)	0.75† (0.46)
Origin = University		(b)	
Origin = Other Firm		(b)	
Dummies for innovation line included	No	No	Yes
N of observations	52	37	50
χ^2	21.64***	19.05***	27.92***

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

b Dummies dropped because they predict success (origin = firm) and failure (origin = univ) perfectly.

To further analyze the role of different partners, we checked which activities firms and universities were most likely to lead *in projects in which they were formal partners of ST*. To this end, we estimated two logit regressions where the dependent variables were dichotomous variables taking the value of 1 if an activity was respectively led or co-led by another firm [regression (2)] or the university [regression (1)], and 0 otherwise. Explanatory variables include activity-level as well as project-level variables, which are conveying more information than simple project dummies. Activities are also characterized by a variable we call "relative position", which is calculated by dividing an activity's position within the project by the project's total number of activities (for example, activity number 3 of a project with 12 activities is characterized by a relative position of 3 / 12 = 0.25).

We cannot assume independence of the error terms across activities because, by construction, different activities may belong to the same project. We thus estimated the regressions as if each project represented a cluster of correlated observations, assuming independence of errors across projects. Results are reported in Table 7. Two main facts appear evident. Universities are significantly more likely to lead activities in which new knowledge is developed ($p < 0.01$), and firms are significantly more likely to lead activities in the last phases of the project ($p < 0.01$). These results suggest that universities are really sought for their capabilities in basic research, whereas firms are sought in the terminal part of basic projects to provide complementary capabilities in the application / experimentation of knowledge developed previously.

Table 7. Results of logit regressions: Leaders of project activities[a]

	University	Firm
Constant	21.75*** (7.88)	2.24 (5.14)
Activity level variables		
Relative position	-0.24 (0.58)	2.02** (0.65)
Activity aimed at developing new knowledge (dummy)	2.86** (0.97)	0.99 (0.97)
Development of technologies and/or processes (dummy) [b]	-13.89*** (0.01)	-5.03† (2.80)
Development of prototypes (dummy) [b]	-13.64*** (1.44)	-14.72*** (1.26)
Definition of SW platform (dummy) [b]	-14.31*** (1.62)	-14.75*** (1.46)
Design of system on package (dummy)[b]	-11.82*** (2.00)	-13.50*** (0.01)
ST is leader of the activity (dummy)	-4.18*** (0.69)	-1.90*** (0.57)
Project level variables		
Cost of the project	-0.36* (0.16)	0.46*** (0.12)
Origin = corporate R&D	3.11 (1.98)	-11.57*** (2.87)
Origin = central R&D	-5.92** (2.16)	Dropped
Origin = same R&D division	2.24 (2.17)	-12.97*** (3.00)
Origin = university	-7.81*** (1.37)	-0.53 (2.46)
Origin = other R&D division	-0.52 (1.91)	-13.24** (4.35)
Origin = other firm	1.94 (1.37)	-2.88† (1.41)
Basicness	14.68** (4.50)	10.42*** (3.27)
Novelty	-1.24 (1.44)	0.20 (0.92)
Strategic importance	4.05*** (1.09)	1.24* (0.65)
Codifiability	1.28* (0.57)	3.82** (1.33)
Dummies for lines of innovation	Included	Included
N of observations	488	428
χ^2	389***	320***

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

[b] Missing technological category: Dissemination.

Table 8 reports the results of the logit regression assessing the factors driving the propensity to engage in R&D contracting with universities and research centers at the project level.[3] The results suggest that ST is likely to contract with universities or research centers in projects in which the knowledge involved is substantially novel ($p < 0.01$) and whose application will lead to strategic results ($p < 0.1$). R&D contracting of some activities appears as a useful mixed solution. Hierarchical control is helpful in preventing deviation from known paths to pre-specified outcomes, but it is not equally helpful in promoting the exploration of unknown paths toward innovative solutions. Although hierarchies have the advantage of more coordinated adaptation, they also have the disadvantage of weaker incentives, due to risk reduction and the impossibility of selective interventions (Williamson, 1985). The parameter estimate of the project's total cost is positive and significant ($p < 0.1$). This result confirms what was argued above, given that projects with large research budgets often undertake research of a broader scope than that involved in lower budget projects (Hall et al., 2003). Results do not show any effect of the project's basicness on the propensity to engage in R&D contracting with universities. As in our previous analyses, specification (2) includes the dummies for project origin and specification (3) those for innovation lines. And again, results are generally robust to these different specifications.

Table 8. Results of logit regressions:
Propensity of R&D contracting with universities or research centers.[a]

	(1)	**(2)**	**(3)**
Constant	-10.54*** (3.11)	-10.10** (3.42)	-12.95** (4.85)
Project cost	0.15 (0.08)*	0.19* (0.08)	0.18* (0.08)
Basicness	-2.77 (2.11)	-2.91 (2.40)	-2.98 (2.11)
Novelty	2.83** (1.27)	2.98* (1.52)	3.22* (1.43)
Strategic importance	1.82* (0.73)	1.30 (0.85)	1.97* (0.87)
Codifiability	0.84† (0.43)	1.07* (0.54)	0.88† (0.49)
Origin = university		(b)	
Origin = other firm		-2.11† (1.18)	
Dummies for innovation line included	No	No	Yes
N of observations	52	48	50
χ^2	27.12***	27.78***	28.76***

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

[b] Dropped because predicts success perfectly.

We also investigated what factors may drive the propensity to contract for R&D in a specific activity. Actually, we believe that this is the most suitable level of analysis for this innovation activity, given that it does not require any formal commitment to the project as a whole from the external actor. Results are presented in Table 9. They show that ST is more likely to engage in R&D contracting in activities where new knowledge is developed ($p < 0.001$) and in the first phases of the project ($p < 0.1$). ST contracts out to universities very specific, basic activities on which to build in the remaining phases of the project.

[3] There are too few cases in the sample to assess significantly the propensity to contract with a firm at the project level.

Project cost and novelty of knowledge maintain their significant and positive effect, while the basicness of the project has a negative effect.

Table 9. Results of logit regressions: Propensity to contract with a university in a given activity.[a]

Constant	-27.70*** (0.01)
Activity level variables	
Relative position	-0.51† (0.31)
Activity aimed at developing new knowledge (dummy)	1.02*** (0.31)
Development of technologies and/or processes (dummy) [b]	13.95*** (1.72)
Development of prototypes (dummy) [b]	14.30*** (1.73)
Definition of SW platform (dummy) [b]	13.30*** (1.76)
Design of system on package (dummy)[b]	14.04*** (1.81)
ST is leader of the activity (dummy)	3.05*** (0.63)
Project level variables	
Cost of the project	0.17*** (0.02)
Origin = corporate R&D	-0.36 (0.32)
Origin = central R&D	Dropped
Origin = same R&D division	-1.27** (0.40)
Origin = university	1.29* (0.57)
Origin = other R&D division	0.58 (0.44)
Origin = other firm	-1.35** (0.45)
Basicness	-1.78* (0.85)
Novelty	2.17*** (0.30)
Strategic importance	0.24 (0.25)
Codifiability	0.72*** (0.11)
Dummies for lines of innovation	Included
N of observations	1123
χ^2	361***

† $p < .10$ * $p < .05$ ** $p < .01$ *** $p < .001$

[a] Standard errors in parentheses.

[b] Missing technological category: Dissemination.

Discussion and conclusions

Our purpose was to understand which characteristics of R&D projects influence their organization and how. The case of STMicroelectronics has helped us to shed some light on this issue. To the best of our knowledge, our data set is the first that allows considering contemporaneously different forms of governance and different partners / contractors (i.e. universities vs. firms). Previous studies (e.g. Pisano, 1990; Sampson, 2003) generally concentrate on alternative decisions (e.g., Make or buy? Which type of alliance, given that an alliance is formed?). In contrast, we are able to explore a broader spectrum of governance forms, being thus able to better understand the drivers of R&D project boundaries. In addition, we are also able to explore the role that different external actors play in an open innovation process.

Though our study has some limitations, we think that these could also highlight some points of strength. True enough, the nature and the size of our sample can only provide preliminary and exploratory results. And although this study clearly has the potential for application in other settings, results may be hardly generalizable. However, given our research design, we were able to obtain exceptionally fine-grained data, sacrificing quantity for quality. Furthermore, analyzing the case of one single firm automatically controls for a series of other effects that are difficult to capture but that may have an influence on innovation strategy and R&D organization, and allows focusing on the only dimensions left: project features.

In this paper, we argued that a project's organizational form depends on its knowledge attributes. We found robust evidence suggesting that the more basic a project, i.e. the more it tends to develop new knowledge as opposed to applying existing knowledge, the more likely it is that external capabilities will be sought. Despite the risk of opportunistic behavior and the uncertainty involved in basic projects, these projects are primarily carried out through cooperation, rather than contracting, to seize learning opportunities. Also, projects conducted in cooperation are characterized by a less tacit knowledge. However, the search for external resources has to be balanced against transaction cost considerations: when project knowledge has a high strategic value, internal development or simple contracting of specific activities are preferred. We also found that universities' capabilities are more likely to be sought in the early phases of a project and in activities aimed at developing new knowledge. Conversely, even in basic projects, partner firms are prone to lead activities belonging to the last phases of the project, and in which the knowledge is applied.

Our results thus show the importance of complementing transaction cost considerations with views that emphasize firms' resources and capabilities. In a dynamic environment, building knowledge may be more important than protecting it. While TCE guards against the hazards that co-developing knowledge involves, it has also to be recognized that firms differ in their resources and that cooperation in R&D can provide more productive and complementary resources as well as valuable opportunities for learning. To further analyze this issue, two apparent contradictions emerging from the data seem to be relevant. First, while both universities and firms are sought in projects in which new knowledge is developed, universities tend to be involved in activities generating new knowledge, while firms are involved in activities in which the knowledge is applied. And second, while there is robust evidence indicating that the higher the strategic value of a project's knowledge, the lower the propensity to cooperate, external partners are still more likely to lead activities in projects of relatively high strategic value. The first apparent contradiction is actually consistent with the fact that universities and firms possess different capabilities, and that these are sought because they are complementary to internal resources. Universities are by definition science-oriented, and their contribution is useful in developing knowledge. Firms possess application-oriented capabilities that are used at the end of the project to complement the first phases of development. This is also consistent with the System-on-Chip product development philosophy typical of the microelectronic sector in which the "silicon know-how" provided by ST is combined with "system know-how" furnished by the customers. The second apparent contradiction highlights how what prevents firms from resorting to external sources of knowledge is actually the fear of opportunistic behavior. There seems to be a cut-off level of strategic importance beyond which the increase in transaction costs outweighs the decrease in production costs. Below this threshold, external partners are given full involvement as the importance of their complementary resources requires, but above this threshold the hold-up risk dominates. Cooperation is thus avoided. To compensate this problem, contracting to universities is widely used in strategic projects. Both the organizational form and the partner's features mitigate the risk of opportunistic behavior. On this point, we would have expected the risk of opportunistic behavior to make ST more reluctant to engage in projects codeveloped with another firm as opposed to a university. This is not the case. Conversely, our results are consistent with those of Casciaro (2003), who suggests that task and strategic uncertainty are predictive of governance structure independently of partner uncertainty.

Our study also highlights some differences between R&D project organization and technology sourcing. While in technology development uncertainty brought about by novelty is generally correlated with external sourcing or development (Steensma & Corley, 2001), this is not the case with R&D projects. The novelty of knowledge does not have a significant effect on the propensity to cooperate. Actually, two different interpretations of uncertainty seem to be relevant in the two cases. In technology sourcing, the perceived threat of commercial failure is the dominant dimension of uncertainty, while the very results of the project are uncertain in R&D. In the former case, there is uncertainty about the value of a given outcome, which will be partially determined by the environment; in the latter, about what the outcome itself will be. Therefore, in the former case partners are sought to share the commercial risk and possibly establish a standard, while in R&D the cost of monitoring potentially facilitates hierarchical solutions. External solutions are partially exploited through contracting. Delmas (1999) finds also that development through alliances is favored over contracting in the case of strategic technologies. Though our data are not directly comparable, we find rather opposite evidence. We submit two interpretations. First, given their more definite nature, technologies allow for more complete contracts and thus alleviate the risk of opportunistic behavior. And second, R&D projects are closer to the heart of a firm’s future, and so the value in jeopardy is higher. Hold-up is more of a concern.

We would also like to suggest some avenues for future research. As we have noticed, the boundaries of innovation are shifting. But there is still little evidence on the effects of the use of external knowledge on performance (Argote et al., 2003). Menon and Pfeffer (2003), for instance, argue that external knowledge is valued only as the result of managerial responses to the contrasting status implications of learning from internal versus external sources, and to the fact that internal knowledge is more readily available and therefore subject to greater scrutiny. In this way, its possible flaws are more easily discovered, while external knowledge is scarcer and thus appears more valuable and unique. The issue of the effect of external knowledge on performance should thus be better scrutinized.

Moreover, although there is some evidence of the complementarity of innovation activities at the firm level (Arora & Gambardella, 1990; Cassiman & Veugelers, 2003), it is still not clear what factors may explain this phenomenon at a more micro level. In other words, what drives the complementarity between innovation activities, i.e. what mechanisms are responsible for these efficiencies created through the integration and combination of different innovation activities? At what organizational level are innovation activities complementary, i.e. at what level are the effects of integration and combination of different activities important? Defining complementarity implies assuming an objective function: is this the same across organizational levels? A lack of empirical data has often prohibited deeper analyses. Information is generally available only at the aggregate level, across firms from very different industries; but disaggregation is critical to understanding the finer details. We need to understand the joint occurrence of innovation activities and evaluate their potential complementarity also at the project level.

To conclude, in this paper we explored how R&D project characteristics condition the governance of an R&D project and its individual activities. Though we are conscious of the exploratory nature of this study, we also feel that it uncovers important new issues, thus contributing to the literature and stimulating future empirical exercises.

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