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Performance Measurement of Collaborative Research and Development: An Exploratory Analysis

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Collaborative research and development (R&D) requires specific management approaches in several aspects including the measurement of R&D performance. This paper aims to contribute to the debate on how performance of different types of collaborative R&D activities should be measured. To this end, we conduct an exploratory research based on case studies, involving four cases of multinational companies in different fields. We show that firms use performance measurement systems for collaborative R&D which are different compared to the ones used for non-collaborative R&D. Furthermore, such performance measurement systems differ depending on the type of collaborative R&D projects that companies are involved in.

Keywords: Collaborative R&D; open innovation; performance measurement systems.

1. Introduction

Research and development (R&D) has long been considered accountable in terms of efficiency, effectiveness, internal and external customer focus and alignment with corporate and business strategy [e.g. Kumpe and Bolwijn (1994); Pearson *et al.* (2000)]. However, scholars are still discussing about how performance of R&D should be measured [Bican and Brem (2020); Loyarte-López *et al.* (2020)]. Many factors encourage managers, policy makers and researchers to develop effective measurement systems of R&D performance [Chiesa and Frattini (2009)]; for instance the increased pace of technology advancements [Bayus (1994); Wind and Mahajan (1997)] and the soaring level of market turbulence, in terms of both customer needs and competitive dynamics [Mohr *et al.* (2005)].

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Multiple perspectives have been suggested in the literature regarding R&D performance measurement, e.g. concerning the criteria and methods that should be adopted to select appropriate metrics and indicators or the dimensions within which performance measurement should be conducted.

In recent years, the increasing importance of external sources of knowledge and technology has challenged the traditional closed approach to R&D and has raised interest among firms in collaborative R&D, also known as Open Innovation [Bogers (2011); Chesbrough (2003); West and Bogers (2014)]. Although collaborative R&D has been always considered an important means to foster innovation [Von Hippel (1988); Pisano (1990); Lane and Lubatkin (1998)], over the last few years, this topic has received more attention as a result of an increasing number of firms adopting a more collaborative innovation model [Huizingh (2011)], also in light of recent trends such as digitalization [Enkel *et al.* (2020)], sustainability [Bogers *et al.* (2020)] or COVID-19 [Chesbrough (2020)]. This approach is based on the idea that valuable technologies and pieces of knowledge are likely to exist and be created both inside and outside the firm's R&D boundaries, such as in other firms, universities and research centers [Chesbrough (2003); Leten *et al.* (2014); Sala *et al.* (2016)]. The concept of open innovation has attracted much attention and become one of the most debated topics in R&D and innovation management. In the seminal book by Henry Chesbrough [2003], he states that Open Innovation is a paradigm assuming that firms can and should use external as well as internal ideas as they look to advance their technology. Among the benefits of adopting Open Innovation, companies may gain benefits from accessing a greater breadth and depth of knowledge [Laursen and Salter (2006)], lower costs of development [Veugelers (1998); Barnes *et al.* (2002); Hagedoorn (2002)], and access to complementary assets and resources that otherwise would not be accessible [Teece (1986); Hagedoorn (1993)]. On the other hand, firms have to face additional elements of risk and uncertainty, such as knowledge spillover [Cassiman and Veugelers (2002)], losing control over their core competencies [Dahlander and Gann (2010)], higher coordination costs [Enkel *et al.* (2009)] and intellectual property (IP) management issues [Chesbrough (2006)].

As firms have started to systematically leverage on external knowledge sources in their R&D activities, measuring the performance of collaborative R&D has become a priority for many firms. This notwithstanding, little attention has been paid in literature to understanding how to properly measure the performance of collaborative R&D. As a result, the challenges of measuring performance of collaborative R&D are still unexplored, with the only exception being a very limited number of contributions. Furthermore, the widespread adoption in recent years of the collaborative innovation perspective has led to an increased number of collaborative projects and to a diversification of these projects in different typologies. Our hypothesis is that this diversity has to be taken into consideration when developing performance measurement systems (PMS) for collaborative R&D projects.

This paper represents one of the first attempts to close this gap by conducting an exploratory analysis aimed at illustrating how firms involved in different types of collaborative R&D activities measure the performance of these processes. The research is based on an empirical multiple case study analysis involving four multinational firms strongly involved in collaborative R&D activities.

This paper contributes to R&D literature by developing a theoretical framework that identifies the fundamental constitutive elements of a PMS for collaborative R&D activities. The analysis shows that, consistently with the extant literature on the topic, firms use PMS for collaborative R&D which are different compared to those used for non-collaborative R&D, with particular reference to the control objects, while the other constitutive elements of the PMS are the same. The second contribution by this paper refers to the design of a PMS for collaborative R&D, which is influenced by the type of collaborative projects, an issue that has previously been neglected by the extant literature. The analysis shows that a significant difference exists in PMS design between explorative and exploitative projects, each one requiring a different PMS regarding the four elements of control objects, dimensions of performance, indicators and measurement process.

This paper is structured as follows. Section 2 reviews the relevant literature on performance measurement of R&D, with a particular focus on collaborative R&D, whereas Sec. 3 develops the theoretical framework used to gather and interpret the empirical evidence. Section 4 illustrates the research methodology and describes how the case studies were conducted. Section 5 presents and discusses the results of the empirical analysis, whereas conclusions and future avenues for research are described in Sec. 6.

2. Literature Review

2.1. *Performance measurement of R&D*

The issue of measuring R&D performance has been addressed by adopting multiple perspectives and by focusing on different units of analysis. On the one hand, a firm-perspective has been adopted, with the aim of measuring the contribution of R&D to economic value creation and competitiveness, thus assuming the perspective of the firm's top management [e.g. Cooper *et al.* (2001)]. On the other hand, a financial market perspective has been used, focusing on the link between a traded firm's market value and its level of R&D investments [Chan *et al.* (1990); Munari *et al.* (2005)]. A third perspective focuses on innovation systems and measures the impact and effectiveness of different (e.g. national or regional) R&D policies [Feller (2002); Foray (2004)].

As regards to the unit of analysis, four streams of research can be identified, as shown in Fig. 1.

A first stream of research looks into the criteria and methods that should be adopted to select appropriate metrics and indicators to accomplish a performance analysis. According to Nixon [1998], metrics and indicators should be easy to understand and to implement, in order to facilitate performance measurement of R&D. Werner and Souder [1997] identified three categories of indicators: quantitative objective indicators, quantitative subjective indicators and qualitative indicators. Other scholars claim the importance of adopting a balanced set of quantitative indicators — to reduce subjectivity of judgment — and qualitative indicators — to capture intangible results [Pappas and Remer (1985)].

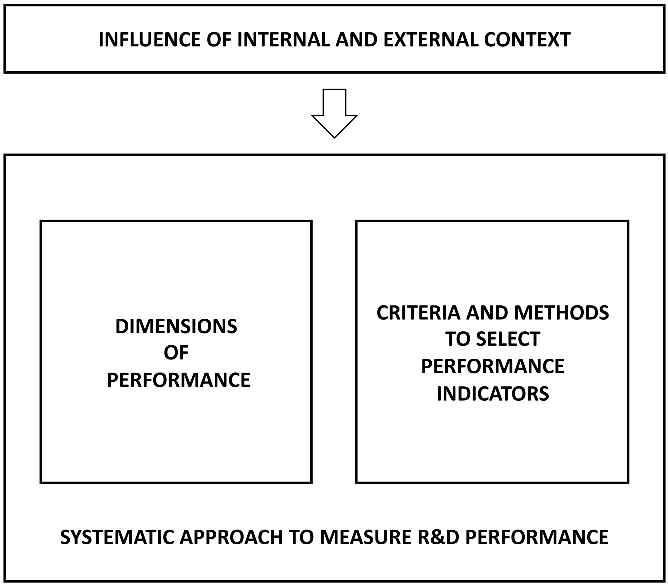

Fig. 1. Four research streams of R&D performance measurement.

A second stream of research focuses on the dimensions within which the measurement of R&D performance should occur. For instance, Griffin and Page [1996] propose customer-based, financial and technical performance as the main dimensions of performance measurement, while Henttonen *et al.* [2015] identify process, market and financial performance measurement dimensions. Pawar and Driva [1999], instead, identify time, cost, quality and flexibility as performance dimensions. Finally, Kim and Oh [2002] identify market-oriented, R&D project-specific and R&D researcher-specific dimensions.

A third stream of research underlines the importance of adopting a systematic approach to measure R&D performance. According to this view, a PMS includes several constitutive elements that are related to one another. Indeed, indicators and performance dimensions should be considered as just parts of a more complex system that also includes a clear identification of the objects of control and a structured measurement process. Moreover, these elements need to be designed together, taking into account the relationships that link them with the objectives of the designed PMS [Kerssens-Van Drongelen and Cook (1997); Kerssens-Van Drongelen and Bilderbeek (1999); Bremser and Barsky (2004); Laliene and Ojanen (2016); Ersoyak and Ozcan (2019)]. Furthermore, the different levels of importance of R&D measures should be taken into account [Salimi and Rezaei (2019)].

Finally, a fourth stream of research analyzes how the internal and the external context influences the design of the PMS. Resource availability, technological innovation and competitive strategies are just some variables that should be taken into account when designing a PMS for R&D [Pappas and Remer (1985); Loch and Tapper (2002)]. All these streams of research have the assumption in common that R&D is conducted according to the traditional, closed approach, whereby new knowledge and technology is developed almost exclusively inside the boundaries of the firm.

2.2. *Performance measurement of collaborative R&D*

To the best of our knowledge, only few scholars have addressed the issue of measuring performance of collaborative R&D processes. Furthermore, few have tried to understand the differences between measuring traditional (closed) R&D processes and the performance of R&D processes that extended beyond the boundaries of the focal firm. A collaborative R&D model requires firms to redesign their R&D PMSs, in order to truly capture the value generated by collaborative R&D [Chiaroni *et al.* (2010)]. The successful implementation of collaborative R&D requires the use of a specific measurement system [Frattini *et al.* (2006); Enkel and Lenz (2009)].

Enkel *et al.* [2011] proposed a framework for measuring and benchmarking the results of collaborative R&D processes organized around the idea that "maturity can be considered a measure of the effectiveness of the process" (p. 1166). The authors identify three main determinants of the level of maturity, i.e. climate for innovation, partnership capacity and internal process, which are positively correlated with effective collaborative R&D activities.

Al-Ashaab *et al.* [2011] developed a balanced scorecard to assess the value of industry–university collaborations. Based on the experiences of ten British companies, they propose a set of indicators for measuring the outcomes of collaborative projects in six dimensions: competitiveness, sustainable development, innovation, strategic knowledge partnerships, human capital and internal business process.

Chien-Tzu and Wan-Fen [2011] identified technology execution, technology exploitation and technology exploration as the most important performance dimensions for collaborative R&D and break them down into sub-dimensions. The study also provides several indicators for assessing the value generated by companies in each sub-dimension and associates a weight to each indicator.

Inauen and Schenker-Wicki [2011] suggested the adoption of three different indicators, i.e. the amount of product innovations, the amount of process innovations and the share of sales related to newly developed products or services, to evaluate the effect of a collaborative R&D model on a firm's innovation performance. Their empirical basis is a set of German, Swiss and Austrian companies.

Ebersberger *et al.* [2012] developed a framework for the evaluation of collaborative R&D activities and their impact on a firm's innovation performance, in order to understand which types of collaborative R&D activities have the greatest impact on innovation performance. The suggested indicators are used to evaluate the impact of collaborative R&D on performance by considering innovation novelty (i.e. whether firms have introduced a product innovation that is new to their market) and share of sales due to innovations. An empirical analysis, covering companies in four European countries (i.e. Austria, Belgium, Denmark and Norway), shows the strong impact of collaborative R&D practices on the firms' innovation performance.

Erkens *et al.* [2014] proposed a metrics-based management toolkit for assessing, controlling and measuring the performance of collaborative R&D activities. The proposed framework takes into account three different dimensions that must be considered to develop and implement a proper PMS for collaborative R&D, i.e. the stage of the collaborative R&D process (distinguishing between upstream, ideation and downstream stages), the type of measures (considering input, process, output and outcome) and the type of use (focusing on instrumental, conceptual and symbolic uses).

A different approach is suggested by Michelino *et al.* [2012], who proposed assessing the value of collaborative R&D projects by quantifying the items that can be exchanged between the firms involved during these processes, i.e. R&D, IP and know-how. Then, the authors advanced two synthetic indicators that can be used to analyze the results of collaborative projects: (i) "the open innovation generated value" — defined as revenues from collaborative R&D + disposals of intangibles from collaborative R&D and goodwill; (ii) "the open innovation consumed value" — defined as costs from collaborative R&D + additions of intangibles from collaborative R&D and goodwill. Similarly, Michelino *et al.* [2015] propose a framework based on the quantification of the inbound and outbound flows in collaborative R&D transactions, focusing on three trading entities in the innovation market (i.e. R&D, IP and know-how), each one characterized by specific costs and revenues. The applicability and usefulness of the framework were validated through an analysis of a sample of 126 global top R&D spending companies in the bio-pharmaceutical industry.

Chen *et al.* [2015] proposed a measurement model of intellectual capital which includes both internal and external dimensions, to make it appropriate for open innovation activities. Both dimensions take into account three elements, i.e. human, structural and relationship capital.

Despite these contributions, plus others that are more focused on the evaluation of R&D networks [e.g. Sala *et al.* (2011)], literature still lacks a clear understanding of how companies measure collaborative R&D activities. In particular, there is a very limited number of studies that adopt an integrated perspective and that help to identify the anatomy of a PMS that is suitable for the different facets of collaborative R&D. In light of this gap in literature, this paper tries to answer the following question: *how could firms measure the performance of different types of collaborative R&D?* In the following section, we illustrate the theoretical framework that we used to guide our analysis.

3. Theoretical Model

We adopt an integrated perspective to the study of collaborative R&D and aim to answer the research question by identifying the anatomy of a PMS that firms could use to measure the performance of their different types of collaborative R&D. The framework developed, which is based on the model presented by Chiesa and Frattini [2009], an improved version of the one developed by Chiesa *et al.* [2008, 2009], is illustrated in Fig. 2.

This framework includes the key elements that should be considered when addressing the problem of measuring R&D performance, and which represents the

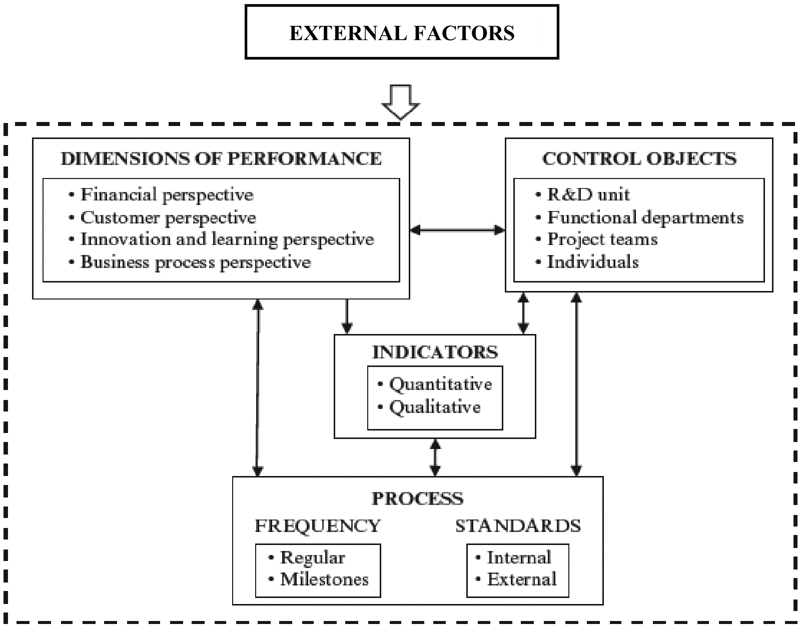

Fig. 2. PMS for collaborative R&D activities [adapted from Chiesa and Frattini (2009)].

constitutive elements of a PMS for collaborative R&D. In particular, the key elements of the PMS are as follows:

- Control objects: this refers to the set of organizational objects (e.g. the R&D unit, the individuals) whose performance is kept under control.
- Dimensions of performance: this refers to the set of dimensions (e.g. financial perspective, customer perspective) within which performance measurement is conducted.
- Indicators: this refers to the set of metrics that are used to measure performance in the different dimensions mentioned above.
- Measurement process: this refers to the target, i.e. the standard, against which the values of the indicators are compared (which may be internal or external to the firm), and the frequency of performance measurement (which may be regular or subject to the achievement of specific milestones).

According to this framework, a proper PMS is characterized by internal consistency between the different constitutive elements and external consistency with non-controllable factors, such as the purposes for which the PMS is used and the characteristics of the firm or the market in which it competes. We chose this framework because it is one of the most complete as it accounts for the many different components of a PMS. Secondly, it points to the importance of the external consistency between the characteristics of the PMS and the contexts in which it is applied. Considering the broad range of collaborative R&D projects a firm can enter, this is a very important aspect to account for. Finally, the framework has already been adapted to many different industries, which points to its broad generalizability [see Chiesa and Frattini (2007)]. In the next section, we provide details of the exploratory empirical analysis that was carried out to answer the research question.

4. Methodology

The empirical analysis was carried out by adopting a multiple case study methodology [Yin (2003)]. This method is consistent with the exploratory nature of the research, and allows in-depth examination of each case and gives the opportunity to study it in its real-world context [Eisenhardt and Graebner (2007)]. Moreover, multiple case studies represent a powerful tool for validating the findings from a single case study, through cross-case comparisons [Eisenhardt (1989)]. The study involved four multi-national firms from different industries that, based on our prior knowledge, were active in collaborative R&D activities. We involved firms that presented the characteristics required (multinational, different industries, active in collaborative R&D) and that we were able to access (convenient sampling).

For confidentiality reasons, these companies are named in the remainder of this paper as Company 1, Company 2, Company 3 and Company 4. Information was collected through primary sources (i.e. interviews with key informants) and enriched through data collection from secondary sources (i.e. internal documents, annual reports, etc.), which enabled us to triangulate data collected through the direct interviews. Table 1 provides a brief description of the four firms included in our sample.

To gather information about the firms and their collaborative R&D activities, we built an interview protocol starting from our theoretical model (see Appendix A). Quantitative and qualitative data was gathered for the purpose of building a comprehensive picture of the PMSs used by each firm. We conducted a total of 14 interviews over a six-month period (see Table 2, showing the roles of interviewees). The interviews lasted between one and three hours and were recorded and transcribed.

To analyze information gathered through the interviews, following Miles and Huberman [1984], we applied two data manipulation techniques: (i) data categorization, i.e. the decomposition and aggregation of data into different groups to highlight relevant characteristics (e.g. aim of the collaborative R&D projects conducted by each firm) and to facilitate comparisons; (ii) data contextualization, i.e. an analysis of contextual factors, not included in the conceptual model, that may reveal unforeseen relationships between events and circumstances. Then, a within-case analysis was performed. The purpose of this preliminary analysis was to consider each case study separately and to systematically document the variables of interest defined in the theoretical model. For each of the four cases, the resulting information was aggregated to obtain a systematic description of the type of collaborative R&D activity undertaken and of the characteristics of the PMS applied. Then, explanation-building procedures were applied to identify the relationships between the type of collaborative R&D activities undertaken by the firms and the characteristics of their PMS. Finally, a cross-case analysis was undertaken to compare the patterns

Table 1. Preliminary information about the firms analyzed.

Name	Industry	Revenues	Employees	Brief description of collaborative R&D activities
Company 1	White goods*	$ 18 billion	≈ 70 000	This company invests on average 3.5% of the consolidated turnover in R&D and innovation activities. In order to increase the company's capability to exploit opportunities from outside, the company decided to create a Strategic External Resourcing (SER) unit under the direct control of the CEO in 2008. This enables the firm to change the way to approach collaborations with third, external parties, moving from a "spot" client-supplier view to a long-term one. During 2011 the SER unit evolved into the External Funding and Open Innovation (EFOI) unit, with the aim of re-designing the partnership management rules and to manage all the collaborations with external partners in a coherent and integrated way. Thanks to this new, more structured approach, the company developed several collaborations (typically in the form of framework agreements or publicly funded projects) with universities and other companies, mainly in order to develop new products, leveraging on their complementary knowledge.
Company 2	Getters materials and high-quality gases	$ 1.95 billion	≈ 1000	This company invests about €150 million in R&D activities every year, equivalent to around 10% of the annual turnover. The main R&D and innovation projects the company engages in can be divided into two categories: pull innovation, with the aim of identifying particular solutions to satisfy defined and explicit customers' needs; push innovation, with the aim of exploring new technological frontiers, in order to satisfy latent problems and to discover new profitable technologies and markets. The company collaborates regularly with third parties in all the stages of the innovation process, especially for "push innovations". These collaborations with partners can be clustered into two categories according to the objective that the firm wants to accomplish: specific research contracts, which aim to explore a specific research area in depth and typically involve one partner; publicly funded projects, which are built around a consortium of partners that participate in a project funded by Italian or European public authorities.

(Continued)

Table 1. (*Continued*)

Name	Industry	Revenues	Employees	Brief description of collaborative R&D activities
Company 3	Tyres	$ 7.5 billion	≈ 35 000	This company invests about 3% of the total turnover in R&D and innovation projects every year. So far the company has conducted about 150 projects in partnership with external partners. These projects are divided into two clusters, called technological field and market field. In the technological field, the company tends to interact with strategic suppliers (through Joint Development agreements) and universities (by means of medium-long term partnerships). On the other hand, in the market field, the main players involved are: car manufacturers, replacement market players and national and international authorities, in public funded research projects. With reference to the former, which is the most relevant field, such collaborations typically aim to improve the performance of its product portfolio, e.g. products with specific features to solve the extreme engineering issues faced during competitions, by integrating partners' expertise and knowledge.
Company 4	Electronics	$ 32.25 billion	≈ 120 000	On average, this company invests 7% of the total turnover in R&D and innovation activities. The company has a centralized unit that manages R&D at a global level. In order to support the research organization in dealing with the creation and submission of research proposals together with third parties, either on a national or international scale, the firm created an ad hoc internal entity. In particular, the company works together with other external companies that are complementary and share the same vision. This entails working with potential strategic partners, future supplier businesses, with the purpose of creating win–win propositions. Thanks to this approach, based on an attempt at collaborative R&D activities, the company draws on the capacities of individuals, organizations, and even small start-ups from all over the world to improve its technological knowledge. Moreover, the company is more and more attracted by the possibility of making its skills and resources available to the outside world, e.g. the firm undertakes contract research for external parties, provides technical facilities and support, and assists them with IP licensing.

Note: *Large electrical goods used domestically such as refrigerators and washing machines, which are typically white in color.

Table 2. Roles of the key informants interviewed during the case study analysis (some of them were interviewed more than once).

Firm	Role of the key respondents interviewed
Company 1	External Funding and Open Innovation Leader
Company 1	External Funding and Open Innovation Analyst
Company 1	Program Technology Manager
Company 2	Corporate Research Manager
Company 2	Knowledge Manager
Company 2	Research & Innovation Manager
Company 3	R&D Project Manager
Company 3	Planning and Control Manager for Technical Functions
Company 3	Open Innovation Manager
Company 4	Head of Venturing, Strategy and Business Development

that emerged in each case study and reach a general explanation of the observed phenomenon. These structured procedures for data collection and analysis, as well as the use of the semi-structured interview guide, helped to enhance the reliability of the research [Yin (2003)]. Despite it not being possible to statistically generalize results from an exploratory case study [Yin (2003)], through this analysis the paper aims to make analytical and theoretical generalizations to be added to the existing body of knowledge regarding performance measurement of collaborative R&D.

5. Results

The multiple case study analysis highlighted the existence of a specific PMS for collaborative R&D activities adopted by each firm, as shown in Table 3.

A first important aspect unearthed by our empirical analysis is that firms use PMSs for collaborative R&D which are different compared to that used for non-collaborative R&D, with reference to the model presented by Chiesa and Frattini [2009]. This is consistent with extant literature on the topic [Frattini *et al.* (2006); Enkel and Lenz (2009); Chiaroni *et al.* (2010)], which suggest that a successful implementation of collaborative R&D requires the use of a specific PMS to truly capture the value generated by collaborative R&D.

In particular, the difference refers to one of the constitutive elements of the PMS, i.e. the control objects. Indeed, the empirical analysis shows that, among the set of organizational objects whose performance is kept under control, the company involved in the collaborative R&D project (i.e. the partner) is typically present within the scope of the PMS, in addition to the project and the individual levels. As explained by the *External Funding and Open Innovation Leader* of Company 1, "*...for us it's crucial to monitor the results achieved by a project, especially in terms of impact on our products' technical performance and, consequently, the company's appeal within the competitive arena...moreover, evaluating the performance of partners enables us to challenge them and select the most valuable ones with which to establish long terms relationships. Thanks to partner evaluation, we can build-up a database that helps us to simplify the partner selection activities for the following collaborative R&D projects, through an early identification of the best ones...*".

Table 3. Main features of the PMS adopted by the firms analyzed.

Company	Control objects	Dimensions of performance	Indicators	Process (Standard)	Process (Frequency)	Main kind of collaborative R&D activities
Company 1	Project Partners	Financial perspective Customers perspective Business process perspective	Quantitative	Internal	Regular (quarterly)	Exploitation
Company 2	Project Individuals	Innovation and learning perspective	Quantitative Qualitative	Internal	Regular (quarterly) Milestone	Exploration
Company 3	Project Partners	Financial perspective Customers perspective Business process perspective	Quantitative	Internal External only in case of new product lines, for which no internal benchmark is available)	Regular (biannual)	Exploitation
Company 4	Project Individuals	Innovation and learning perspective	Quantitative Qualitative	Internal	Regular (quarterly)	Exploration

As far as the other constitutive elements of the PMS are concerned, the empirical analysis shows that companies adopt the same PMS for the evaluation of collaborative and non-collaborative R&D.

A second important aspect unearthed by our empirical analysis, which has not been analyzed by extant literature on the topic yet, is that firms use PMS for collaborative R&D which are different depending on the type of collaborative R&D projects they are involved in. In particular, our analysis brings into light a difference between exploitative and explorative projects, each characterized by different objectives [Levinthal and March (1993); March (1991); Hoang and Rothaermel (2010)].

5.1. *PMS for collaborative R&D — Explorative projects*

Through explorative projects, firms aim to collect new knowledge from outside their boundaries, without a specific market or product application in mind.

As regards to the objects of control, the evaluation of explorative collaborative R&D is carried out at the project and individuals levels, in order to analyze the effectiveness of the projects in gathering new knowledge from outside the company's boundaries and, on the other hand, the innovation capabilities of the individuals. For example, Company 2 adopts an incentive system to manage and stimulate its employees. At the beginning of each year, Company 2's managers define a list of objectives that cover four areas (People, Process, Customer and Economics) for the so-called key individuals. In the case of employees involved in explorative collaborative R&D activities, most of the attention is put on the researchers' capability in developing new knowledge. Moreover, Company 2 has recently decided to implement a Knowledge Management System (KMS), which aims to evaluate the quality and the size of each researcher's network. Company 2 believes that this investment will increase the chance of establishing new collaborations with external partners, motivating the researchers as well.

The performance dimensions used in explorative collaborative R&D mostly focus on how collaborative R&D activities support the growth of innovation and learning abilities. Consistently with this, the types of indicators used to measure each dimension of performance especially focus on the learning ability of the company and are both quantitative and qualitative. For example, Company 4 measures the effectiveness of its collaborative R&D activities in two ways, i.e. considering the number of IP creations and the number of technology transfers. Technology transfers represent opportunities that are transferred from the R&D department to the business lines and could therefore be seen as a proxy of the firm's ability to innovate by leveraging knowledge from outside the company's boundaries. As a result, the number of technology transfers can be truly interpreted as a means used to effectively drive the quality of the company's research. During the interviews, Company 4's Senior Director of Strategy and Business Development Group underlined the strategic relevance of collaborative R&D, but also of a structured measurement system: "For our Company, the Collaborative R&D is extremely important ... the Strategy and Business Development group has a specific modus operandi, in order to help the researchers to define and exploit opportunities in a very specific way ... ".

Regarding the standards against which the performance indicators are evaluated, explorative R&D collaborations are typically evaluated against an internal standard, i.e. comparing the achieved results with those attained in traditional, closed R&D projects, with the aim of highlighting the value created through the application of a collaborative approach. As an example, the central entity that manages R&D activities within Company 4 tries to improve performance related to the two aforementioned indicators over time, by defining new targets in all the research programs every year.

Finally, as regards to the frequency of measurement, explorative indicators are evaluated both on a regular basis and after the achievement of a milestone. Regarding this feature, Company 2's Corporate Research Manager explain that "... such a hybrid approach depends upon the different dimensions of performance under evaluation within each collaborative R&D activity ... the ones related to the business process perspective, e.g. the comparison between actual project costs and budget costs, are regularly evaluated, while the ones related to the individuals and their motivation are evaluated by milestones, i.e. the achievement of the different stages of a project ...". For example, in Company 2 a dashboard of indicators — the most important one being the budget cost over actual cost ratio — is prepared for each project and shown to the Corporate Research Manager four times a year, to inform top management about current expenditures.

5.2. *PMS for collaborative R&D — Exploitative projects*

Through exploitative projects, firms aim to leverage outside knowledge to incrementally build on internally available know-how and to develop products and services that meet specific market or product-related objectives.

In terms of the objects of control, our empirical analysis shows that exploitative R&D activities are typically evaluated at the level of each single project, in order to evaluate the outcomes and the required effort by the company, and at the level of the partners involved, with the aim of analyzing the partners' performance.

The performance dimensions used in exploitative collaborative R&D focus on economic and financial aspects, also taking into account customers and business process perspectives (i.e. the level of efficiency that characterizes the different processes). Therefore, indicators used to measure each dimension of performance are typically quantitative. For example, the indicators adopted by Company 1 for the evaluation of each project are as follows:

- Number of projects completed in the case of product innovation.
- Specific metrics like number of victories, numbers of races, and performance registered during the races for competition innovations.
- Number of certifications for first equipment innovations.

Moreover, in line with the importance associated with partner evaluation by Company 1, specific objectives (i.e. target value) are defined for each indicator during the project start-up phase. The scores associated to each partner are depicted in radar diagrams in order to evaluate two different perspectives: (i) partnership assessment, i.e. partner performance compared to target dimensions; (ii) current assessment, i.e. partner performance compared to results achieved by other partners in the project (in case of multi-partner collaborations).

In terms of the standards against which the collected performance indicators are evaluated, the performance of exploitative R&D collaborations is usually evaluated against an internal standard, i.e. comparing the achieved results with those attained in traditional, closed R&D projects. The Planning and Control Manager for Technical Functions at Company 3 highlights that "... The output of the projects, in terms of their impacts on product portfolio performance, is evaluated against the current performance of the products offered and the traditional closed R&D projects. However, in the case of a new product line, the output of the projects is compared to the product of the market leader ...".

Finally, the exploitative indicators are typically evaluated on a regular basis, despite a difference in frequency due to the choices implemented by each firm.

6. Conclusions

This paper contributes to the increasing debate on the design of a PMS for collaborative R&D activities, by developing a theoretical framework that identifies the fundamental constitutive elements of a PMS for collaborative R&D activities. Building on the model developed by Chiesa and Frattini [2009] and by adopting an integrated perspective in developing the framework, the paper aimed to shed light on how companies should measure collaborative R&D activities.

The exploratory empirical analysis shows that, consistently with extant literature on the topic, firms use PMS for collaborative R&D which are different compared to those used for non-collaborative R&D, with particular reference to the control objects. The other constitutive elements of a PMS are not affected by the collaborative or non-collaborative nature of R&D activities.

In addition, it emerges that the design of a PMS for collaborative R&D is influenced by the kind of collaborative projects: exploitative projects, aimed at know-how improvement, and explorative projects, aimed at know-how creation require different PMS. Exploitative projects and explorative projects affect the constitutive elements of the PMS, i.e. dimensions of performance, control objects, indicators and measurement process.

Regarding dimensions of performance, through exploitative collaborative projects firms find new ways to improve what they already do, enhancing the existing body of knowledge and reducing cost and/or time of development (i.e. following a financial and customer perspectives) or improving internal efficiency (i.e. following a business process perspective). Through explorative collaborative projects, firms tend to develop new bodies of knowledge, thus evaluating projects from an innovation and learning perspective.

As regards to control objects, both exploitative and explorative collaborative projects are evaluated at project level. In addition, explorative collaborative projects are also evaluated at individual level, in order to evaluate the innovation capabilities of the individuals, while exploitative collaborative projects are also evaluated at the partners' level, in order to analyze their performance.

In terms of indicators, exploitative collaborative projects tend to be evaluated with quantitative indicators, whereas the evaluation of explorative projects relies on a mix of quantitative and qualitative indicators.

A last difference emerges regarding the measurement process, given that the performance of exploitative collaborative projects is evaluated on a regular basis against the performance of internal R&D projects performance, whereas the evaluation of the performance of explorative projects (measured through quantitative and qualitative indicators) is carried out on a regular basis against itself, i.e. analyzing how it evolves over time.

This framework was built with an empirical analysis that involved four companies that have been active in different kinds of collaborative R&D activities. We acknowledge the limit of this non-probability sampling choice and believe that further research can be useful to verify and strengthen our results. However, the results of this paper can benefit R&D management scholars and managers of innovative firms.

First, our results emerged from the analysis of firms operating in different industries, thus providing support to the generalizability of our findings beyond only one industry. Secondly, our results are based on and further develop a model [Chiesa and Frattini (2009)] already established both in literature and in practice; and the changes introduced in this work are relevant but incremental. Thirdly, the paper provides a set of guidelines for designing a PMS according to the type of collaborative R&D activities conducted, but these guidelines and the resulting PMS can be readily adapted to different collaborative projects and contexts. Finally, our results are consistent with current literature on R&D performance evaluation that suggests that different criteria must be adopted depending on the types of activities that are evaluated through the PMS [e.g. Ebersberger *et al.* (2012), Michelino *et al.* (2015)].

The paper also brings into light some implications for managers and, especially, for those in charge of leading the R&D and innovation activities. Firstly, the developed framework represents one of the first formalized tools for the evaluation of collaborative R&D activities. Managers may use it to foster communication and coordination within their R&D and innovation departments, enhancing the performance of their technical professionals, and motivating them to measure the contribution to the firms' innovation activities. In addition, this work gives managers a series of guidelines for designing a PMS according to the type of collaborative R&D activities in place, as a one-size-fits-all approach does not appear to work in collaborative R&D performance measurement. Moreover, this work provides indications for firms about how to customize their PMS following the guidelines and the logic behind them. The customization process in itself could be another way to involve the R&D personnel and to foster communication and coordination inside and beyond the R&D department.

Of course, the paper suffers from a number of limitations, which will hopefully open up avenues for future research on the topic. First, as already mentioned, this study has an exploratory nature and its results cannot be generalized easily. In particular, one of the main avenues for future research on the topic refers to the development of PMS for collaborative R&D activities in smaller firms (i.e. small and medium enterprises — SMEs), given the increasing relevance of collaborative R&D activities for such firms [van de Vrande *et al.* (2009); Lee *et al.* (2010)]. Secondly, given that a firm can collaborate with different types of players in their collaborative R&D activities, such as customers [Urban and Von Hippel (1988); Souder *et al.* (1997); Brockhoff (2003)], suppliers [Ragatz *et al.* (1997); Van Echtelt *et al.* (2008)], universities and research institutes [Hise *et al.* (1980); Santoro and Betts (2002)], it would be interesting to investigate whether and to what extent the type of players involved in collaborative R&D activities has an influence in developing a PMS for such activities. Finally, future research should explore the existence of a relationship between the development of PMS for collaborative R&D activities and the companies' overall success.

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