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**GESTÃO DE PROJETOS DE P&D
COM DIFERENTES TIPOS DE FONTES DE CONHECIMENTO**

**MANAGING COLLABORATIVE R&D PROJECTS
WITH DIFFERENT TYPES OF KNOWLEDGE SOURCES**

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**SÃO PAULO
2018**

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WITH DIFFERENT TYPES OF KNOWLEDGE SOURCES**

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To my family and all people that support the
development of scientific knowledge and
work for a more collaborative world.

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“Sem o entendimento de nós mesmos e dos outros, sem a empatia que nos une aos outros, não pode existir nenhuma sabedoria, nenhuma beleza" (Montero, 1951/2016).

“Without the understanding of ourselves and others, without the empathy which joins us with others, there can exist no wisdom, no beauty” (Montero, 1951/2016).

ABSTRACT

Barbosa, A.P.F.P.L (2018). Managing collaborative R&D with different types of knowledge sources (Ph.D Thesis). Faculdade de Economia, Administração, Contabilidade e Atuárias, Universidade de São Paulo, São Paulo, Brazil.

While several studies have shown the existence of dissimilarities among diverse types of external knowledge sources, little attention has been given to identifying the project management success factors that are most suitable for each of them. Based on a quantitative exploratory approach, this study examines the relationship between Success Factors in Collaborative R&D project management and project performance, examining evidence on the dichotomy of Science-based and Market-based knowledge sources. *Performance* here is a multidimensional construct bringing together several dimensions: *Budget, Time Schedule, Technical Quality, Patents, Publications* and *Overall Success Performance*. The Project Management set of success factors evaluated were related to *Clearly Planning the Project, Mutually Agreeing on Project Plans, Progress Monitoring and Effective Communication*. To optimize performance, our findings strongly suggest the need for an R&D project management approach contingent on external knowledge source. More specifically, *Clearly Defining Expectations, Objectives and Responsibilities* and *Jointly Agreeing on Human Resources Characteristics* improve the *Technical Quality* of the projects with Science-based sources. In projects with Market-based sources, *Discussing the Sources of Conflict, Defining Appropriation Issues and Milestones, and doing these together* improve the *Schedule* performance. No association of performance improvement with *Project Progress Monitoring* was identified in projects made exclusively with Science-based sources. Success factors for *Effective Communication* also show some different effects on performance by knowledge sources. *Informal Communication* is positively and significantly correlated to the *Technical Quality* of the project for Science-based sources; however, *Having Pre-Defined Communication Strategies* is correlated to performance only for Market-based sources. These findings contribute to practice in *Collaborative Project Management*, identifying success factors to be emphasized, depending on the type of knowledge source involved in the project.

Keywords: Innovation; Open Innovation; Technology Collaboration; Project Management; Research and Development.

RESUMO

Barbosa, A.P.F.P.L (2018). Gestão de projetos de P&D com diferentes tipos de fontes de conhecimento (Tese de doutorado). Faculdade de Economia, Administração, Contabilidade e Atuárias, Universidade de São Paulo, São Paulo, Brasil.

Enquanto diversos estudos identificaram que existem dissimilaridades entre os vários tipos de fontes externas de conhecimento, pouca atenção foi dada a identificação dos fatores de sucesso em gestão de projetos que são mais adequados a cada uma delas. Com base em uma abordagem exploratória quantitativa, este estudo examina a relação entre os fatores de sucesso em gestão de projetos de P&D em colaboração e o desempenho desses projetos, evidenciando a dicotomia entre projetos realizados em colaboração com fontes de conhecimento de base científica e de base de mercado. Nesse estudo, *Performance* é um construto multidimensional que reúne várias dimensões: *Custo, Prazo, Qualidade Técnica, Patentes, Publicações* e uma *Avaliação Geral de sucesso do resultado do projeto*. O conjunto de fatores de sucesso em Gestão de Projetos avaliados estão relacionados a: *Clareza no planejamento do projeto, Acordo conjunto sobre os planos do projeto, Monitoramento do progresso do projeto e a Eficácia na comunicação*. Para otimizar a performance, nossos resultados reforçam a necessidade de uma abordagem contingencial em gestão de projetos. Mais especificamente, em projetos realizados em colaboração com fontes de conhecimento de base científica, a *Clara definição de Expectativas, Objetivos e Responsabilidades* e o *Acordo conjunto sobre as características dos recursos humanos* melhora a *Qualidade Técnica do projeto*. Em projetos realizados com fontes de conhecimento base de mercado, *Discutir a fonte do conflito, Definir assuntos de apropriação e metas e fazer isso conjuntamente*, melhora a performance relacionada ao *tempo planejado* para o projeto. Nenhuma associação de melhoria de performance relacionada ao uso de *Monitoramento do Progresso do Projeto* foi identificada em projetos feitos exclusivamente com fontes de base científica. Ações para a *Eficácia da comunicação* também apresentam alguns efeitos diferentes na performance segundo a fonte de conhecimento envolvida, já que *Comunicação informal* é positiva e significativamente correlacionada à *Qualidade técnica* do projeto na amostra de projetos realizados com fontes científicas; entretanto, ter *Estratégias de comunicação pré-definidas* é o que se correlaciona com a performance apenas em fontes de base de mercado. Tais resultados contribuem para a prática de gestão de projetos em colaboração, auxiliando a identificar fatores de sucesso a serem enfatizados considerando a fonte de conhecimento como variável moderadora.

Palavras-Chave: Inovação; Inovação Aberta; Cooperação tecnológica; Gestão de Projetos; Pesquisa e Desenvolvimento.

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1. INTRODUCTION

Innovation has the potential to improve people's lives, to increase companies' competitiveness, and to disrupt an entire sector. At the center of its success is knowledge — a dynamic, complex and dispersed asset that challenges management. In order to foster technological innovation, companies invest in knowledge creation through R&D. These investments, in a global perspective, have been growing, at least over the last 30 years (Figure 1.1), driven by high-tech industries (pharmaceuticals & biotechnology; technology hardware & equipment; automobiles & parts; software and computer services, see Figure 1.2) and concentrated in a small group of companies as 50 companies account for 40% of global R&D (European Union, 2016).

Figure 1.1: Gross domestic spending on R&D – OECD Countries

Source: Adapted from OECD (2014)

While investment can help solve many problems, it is not the solution for innovation challenges. It is already known that increasing the expenditure on knowledge generation (in terms of R&D) will not guarantee a better return on investment for the company. In general, reports show that some companies keep increasing their investment in R&D over their growth rates (European Commission, 2016); however, the return on their investment does not follow the same path (especially in sectors that are R&D intensive) (Figure 1.2). And, as some examples show, companies that have spent less on R&D than their competitors can even

overcome their dominance (like Apple, which spent a third less on R&D than Nokia) (Dodgson, Gann, & Phillips, 2013). Considering these scenarios, scientists already know that there is something more than just money that should be added to this equation to improve the innovation efficiency of companies.

Figure 1.2: Worldwide growth rate of R&D and net sales

Source: European Commission (2016, p. 10)

One form that companies have been using to leverage their innovation results is R&D Collaboration — a phenomenon that has been increasing since the 1960s (Hagedoorn, 2002), through which companies have access to new and complementary knowledge and technologies so they can solve complex problems faster and spread the cost of R&D among different parties (Chesbrough, 2003). However, what could be a great solution for efficiency and competitive gains is not that easy to achieve as *R&D collaboration* results in adding more complexity to project management and may not achieve the expected goals. This failure makes us wonder how collaborative project management could be improved.

Some steps forward in understanding how to improve collaborative project management have been taken. On one hand, project management success factors in R&D collaborative projects have been identified (Barnes, Pashby, & Gibbons, 2006). On the other hand, it seems that they are not the same for different knowledge sources (Mora-Valentin, Montoro-Sanchez, & Guerras-Martin, 2004). In this setting, using the same project management pattern for different types of partners results in different performances (Du, Leten, & Vanhaverbeke, 2014). However, research has not yet shown the relation between project management success factors in collaborative R&D and project performance and R&D outputs specifically in order

to understand differences in this relation according to the types of external knowledge sources involved in the project.

This contingent approach to project management in collaborative projects enables managers to select the most suitable practices according to project characteristics (Lippe & vom Brocke, 2016). This thesis, which looks at improvement in project management execution in collaborative projects, addresses this challenge, as will be clarified in the following section.

1.1 Limits of existing research and the research question

The studies related to collaborative R&D include a variety of literature streams and diverse terminology. It is a literature that is being built, in a broader sense, to understand how interorganizational collaboration can improve innovation and improve efficiency and efficacy in the innovation process. There are very interesting intersections with consolidated research streams that are being developed and are helping to fill research gaps. However, there is still a lot to be done.

First, it is important to clarify what this study adopted as a definition for collaborative R&D projects. They are understood as temporary organizations where two or more knowledge sources¹, that remain independent economic agents, share R&D activities (Hagedoorn, 2002).

One current limit of this study is at the level of analysis. Most of the literature regarding collaborative R&D is at the organizational level (Chesbrough, Vanhaverbeke, & West, 2014), though these collaborations happen through projects. Prior studies identified that innovative performance in collaborative projects is influenced by diverse factors like number of partners (Laursen & Salter, 2006); internal R&D activity (Chen, Vanhaverbeke, & Du, 2016); and balancing of the portfolios of partners (Duysters & Lokshin, 2011; Levine & Prietula, 2014). However, the findings are related to the firm level and need more fine-grained information to open up the black box of execution issues and help improve collaborative project performance. At the organizational level, the research has advanced a great number issues, but there are some questions that can better be investigated at the project level. Studies at this level offer the chance to understand the peculiarities of the project as projects can differ in many aspects such as the level of innovativeness, the team composition, and leadership. Moreover, “a detailed analysis

¹ In this study, we decided to use knowledge sources and not “firms” or “partners” as collaboration can be developed with customer, individual actors, and knowledge specialists.

of open innovation in the project level extends the list of critical success factors which determine performance” (Chesbrough et al. (2014, p. 118)).

Another limitation of the literature is that of *R&D Collaboration and Performance* (usually firm performance). There is no consensus regarding this relation (Chesbrough et al., 2014). Study findings, in general, make a positive association between *R&D Collaboration* and firm performance (René Belderbos, Carree, Diederer, Lokshin, & Veugelers, 2004; Chen et al., 2016; Faems, Van Looy, & Debackere, 2005; Grimpe & Kaiser, 2010). However, they usually show that there is some limit for the relation to remain positive, which is explored by considering diverse variables like search strategy (Laursen & Salter, 2006), alliance complexity (Duysters & Lokshin, 2011), type of knowledge acquisition; type of knowledge source (Du, Leten, & Vanhaverbeke, 2014; Kang & Kang, 2010), and partners’ technological relatedness (Petruzzelli, 2011). Most of the studies were conducted at the firm level, and because of this, the performance measurement that is being used involved variables that are not directly related to the project performance. Usually performance measures used are firm outcomes and not R&D outputs. In this context, the collaborative R&D performance success is being influenced by other functions of the firm and activities like marketing and sales. As a result, the success that is being measured is influenced by a myriad of factors that are not directly related to the collaboration.

At the project level, evidence already shows that the formality of project management (use of planning, monitoring and controlling mechanisms) has different impacts on the project’s financial performance regarding the external knowledge source involved in the R&D project (Figure 1.3) (Du, Leten, & Vanhaverbeke, 2014); that external R&D partners play distinct roles in speeding up project first research transfers (Du, Leten, Vanhaverbeke, & Lopez-vega, 2014); and that prior cooperation and geographical distance between the knowledge sources has a positive impact on the project innovative outcome (Petruzzelli, 2011). This evidence guided us to a contingent project management approach, which is the interplay between the project management needs and the best suited management approach (Howell, Windahl, & Seidel, 2010). In this research stream, the “project management is considered the structural variable that must be adapted based on a certain internal and contextual contingency in order to optimize the effectiveness of project management” (Lippe & vom Brocke, 2016, p. 78).

Figure 1.3: Marginal effects of Market-based and Science-based partnerships for different values of project management.

Source: Du et al, (2014, p. 836).

Du et al. (2014) have provided insights that managerial practices for R&D projects might need different approaches according to knowledge sources. The findings of their study at the project level help to defend a contingent project management research stream where the variation can be in the type of knowledge source used. Despite providing this evidence, their research did not focus on identifying what should be contingent in the project management practices. And, to our knowledge, no study has yet related different practices used to project performance and knowledge sources.

Bearing this in mind, we can now summarize the main limitations of current research on Collaborative R&D:

- Little collaborative R&D research at project level.
- Diverse results regarding the relation of Collaborative R&D projects and performance.
- Evidence that factors related to project management have diverse influence on performance according to knowledge sources types, but there is no study relating the practices effectively used in the R&D collaborative project and the project performance by knowledge source types.

Following this, we believe that there is an opportunity to explore the relation between project management in R&D collaborative projects and their performance but considering this analysis by knowledge source type. The assumption behind grouping the knowledge sources into Science-based and Market-based areas lies in the previous literature that already identified

the different effect of using a formal management tool according to these two types of knowledge source (Du, Leten, & Vanhaverbeke, 2014). In addition, the literature shows evidence of fundamental organizational dissimilarities between diverse types of knowledge sources, more specifically between University and Industry (Bjerregaard, 2010; Estrada, Faems, Martin Cruz, & Perez Santana, 2016).

The following research question guides this study:

Do project management success factors differ in collaborative R&D projects, depending on knowledge source involved in the project?

Besides adding more fine-grained knowledge to the Project Management literature (and more specific Collaborative R&D project management), this study has a very practical implication in helping to identify project management success factors which are suitable for each type of knowledge source, and, consequently, to improve project performance.

1.2 Research framework

To answer the research question presented above, the following research framework was developed. Each variable will be explored in the methodology section.

Figure 1.4: Research Framework

Source: Elaborated by the author

1.3 Thesis structure

This study is organized into eight chapters. The first chapter introduces the context of the study, addressing the limits of the research in collaborative R&D, helping to understand the research question and the expected contribution of the study. The research framework is then presented.

Chapter 2 and 3 present a review of the literature, starting with an overview of the research on Collaboration in R&D where a bibliometric study was developed. Certain research streams were identified, and another bibliometric study was made to verify the advances, specifically in research on Collaboration in R&D and Performance. After this, a review of publications on Project Management and R&D collaborative projects helped to identify the main constructs to build the variables used in this research.

Chapter 4 describes the methodology used, puts forward the hypothesis, and details the operationalization of the framework. The research instrument used for the survey and methodological decisions on data collection and analysis are described, thereby explaining the research process.

Chapter 5 presents the data analysis, including a detailed description of the sample. The analysis was conducted in two steps. First, a comparison between the Success Factors used by the projects with The Best and The Rest performance helped to describe the use of each success factor by projects made with each knowledge source type and by performance. Then the Pearson correlation results are presented by performance measure, with a figure showing the main findings.

Chapter 6 discusses the findings with the existing literature on *R&D Collaboration* in Project Management to reinforce the main findings and highlight the divergence and convergence to this literature.

Chapter 7 concludes the study and presents the main contributions and implications for theory and practice.

Finally, Chapter 8 describes certain limitations, which are mainly related to the exploratory quantitative approach, and suggests opportunities for future studies.

2. MANAGING COLLABORATIVE R&D PROJECTS

The research on managing collaborative R&D projects includes diverse consolidated research streams and new ones, and efforts to increase the integration with these consolidated streams are being made (Chesbrough et al., 2014). The literature was reviewed to identify the main papers and research streams connected to Collaborative R&D research. With the increasing number of papers being published in any given field, it is difficult to give as much attention to individual research papers as previously. “By having data automatically analyzed and visualized, the researcher can identify the core publications, publication trends, common research trends and the direction of latest research” (Knutas, Hajikhani, Salminen, Ikonen, & Porras, 2015, p. 189). So, the scientific community is using software analysis tools, which are becoming more user friendly. This thesis used some of these tools to give an overview of the literature dataset and then deepen the investigation on core publications and the latest research.

The following protocol was used:

- (i) Research on Web of Science Base
- (ii) Topic: Collaboration (128.589 documents were identified)
- (iii) Refined by: R&D and Articles in Business and Management (577 papers)
- (iv) Co-citation analysis (cited references) using the software VOS (van Eck, Waltman, Dekker, & van den Berg, 2010): the minimum number of citations of a cited reference to be considered was 20 (from 19,196 cited references, 87 meet the threshold).
- (v) Co-occurrence analysis (keyword) using the software VOS: the minimum number of occurrence of a keyword was 15 (of 2,130 keywords, 59 meet the threshold – The words Research-and-development and Collaboration were excluded, and also their variations like R&D).
- (vi) Publication statistics using the web-based analysis server NAILS (Knutas et al., 2015): identification of main papers, periods and authors.

The bibliometric study, using both the co-citation map VOS (which stands for visualization of similarities) and the literature analysis NAILS (statistical and network analysis) was conducted to help construct an overview of the state of Collaborative R&D research.

Figure 2.1 shows an increasing number of publications over the last 20 years, with the specialized literature starting to flourish during the 1990s but only receiving attention in the 21st century.

Figure 2.1: Publications on *Collaboration* + R&D by year.

Source: Elaborated by the author

Considering the number of published articles in the dataset and by the total number of citations, a list of the most popular journals is shown in Figure 2.2. Notice that the leading journals are important ones in the innovation field, which provides some evidence of the interest in the theme and opportunities to publish. Some of these journals published special issues in areas related to *R&D Collaboration*, and Research Policy was one of them.

Figure 2.2: Most popular publications by number of published articles and total number of citations.

Source: Elaborated by the author

Using the software VOS, a Keyword network was created, based on co-occurrence (Figure 2.3). The format of the map shows that the Keywords are not concentrated in a certain area of the map, and this suggests that there is some overlap between issues.

The keyword *Co-occurrence Network* provides a first impression of certain research streams associated with the theme we are interested in. The main keywords in each cluster are identified below:

- Yellow cluster: *Strategic Alliance, Cooperation, Partnership, Joint-Ventures.*
- Green cluster: *Performance, New Product Development, Dynamic Capabilities.*
- Red cluster: *Technology, Industry, Development Cooperation, Patents, Technology transfer.*
- Blue cluster: *Absorptive-capacity, Open Innovation, Product Innovation, Competitive Advantage.*

Figure 2.6: Density visualization by author co-citation

Source: Elaborated by the Author

Simulating this data with publications from the last 10 years (2006-2016), there is little change in the papers that have the higher weight, confirming that the main research streams are those most related to *R&D Collaboration*. What we can notice is higher centrality and weight of publications in Chesbrough (2003) and Powell, Koput and SmithDoerr (1996) (Figure 2.7). This proximity is explained by the growing attention to an increasing interest in *Ecosystem Studies* in *Open Innovation* related studies. However, a group of papers that were published after 2000 appear in yellow. It is interesting that this group is the most recent in terms of publications but is frequently cited. A deeper examination of this papers (René Belderbos, Carree, Diederer, et al., 2004; René Belderbos, Carree, & Lokshin, 2004; Faems et al., 2005; Miotti & Sachwald, 2003; Tether, 2002) showed that they are interested in partner heterogeneity, an issue that is part of this research.

Figure 2.7: Co-citation maps from the last 10 years of *R&D Collaboration* research

Source: Elaborated by the Author

From this overview, we could identify some main research streams related to the research on *R&D Collaboration*. The field is being studied through different lenses, the most connected being *Product Development* literature, *Strategic Alliance*, *Knowledge based-view*, *Network Theory*, with increasing attention given to this last area and to *Open Innovation*. It is important to recognize that *Performance* has a recurrent participation in studies related to *R&D Collaboration* and that the studies of Cohen and Levinthal (1990) have a considerable influence on this field. Last but not least, the appearance of papers concerned with the heterogeneity of partners in more recent data reinforces the fact that this theme has recently been receiving more attention. And we could also realize that the *Project Management* literature did not appear to have a strong relation with *R&D Collaboration* studies, which can be an opportunity to bring a consolidated research stream to contribute to solve challenges in *R&D Collaboration*.

2.1. Research on *R&D Collaboration* and *Performance*

The previous section showed that *Performance* is a very common keyword in studies related to *R&D Collaboration*. Bearing this in mind, it is important to understand the main findings of the association between *Performance* and the use of *R&D Collaboration* that the literature already provides. Previous publications show some evidence that there is no consensus regarding this relation (Chesbrough et al., 2014). This section will explore the findings in this issue.

To identify the papers published on this theme we made a search in the Web of Science data base using the following protocol:

- (i) Topic: *Collaboration*
- (ii) Refined by: R&D
- (iii) Refined by: *Performance* and Articles on Business and Management (287 papers)
- (iv) The abstracts of these 287 papers were read, and those that made a relationship between *R&D Collaboration* and some performance measurements were considered.
- (v) Publication statistics using the web-based analysis server NAILS ((Knutas et al., 2015): identification of the main papers (the most important papers are identified using three importance measures: 1) in-degree in the citation network, 2) citation count provided by the Web of Science and 3) PageRank score in the citation network. The top 25 highest scoring papers were identified by separately using these measures. The results are then combined, and duplicates removed. Results are sorted by in-degree, and ties are first broken by citation count and then by the PageRank, which was used to build a table with the main findings.

The same protocol was made for the *Cooperation* topic (258 papers) replacing *Collaboration*. The duplicated papers were removed. After this, considering the highest scoring papers from both sets of data, the abstracts were read, and those that made some relation between *Interfirm Collaboration* (collaboration with an external source) and *Performance* were considered. *Collaboration* was the topic with the most number of papers, as expected. Finally, we found 24 papers presenting some relation between *R&D Collaboration* (or *Cooperation* in a few cases) with some *Performance Innovation* measurements. The complete table is presented in Appendix A. The abstracts from other papers presented in the Web of Science data were read, and those that made the specific relation were also considered. From this review we could identify the main variables relating *R&D Collaboration* and *Performance*, and they are now analyzed.

As the prior literature suggested, there is no consensus regarding *Collaboration* with external partners and *Performance*. However, what we could notice from the literature review is that this relation is influenced by a myriad of factors, which helps to justify the differences in the findings. One of the most influential papers in this sense was published in 2006 by

Laursen and Salter (the most cited paper in our search). Knowing that firms were increasingly drawing in knowledge from external sources in their innovative performance, these authors tried to understand the role of external search strategies in shaping innovative performance (Laursen & Salter, 2006). Their findings provide some evidence that partnership with external sources for innovation activities is not always positively related to the firm's innovative performance. This relation is influenced by the level of openness, which means how deeply (level of using the same source) and widely (number of external sources) the company searches for external partners. Following a similar idea, Duysters and Lokshin (2011) argue that firms face a certain cognitive limit in terms of the degree of complexity they can handle. Their study relates alliance complexity (measured by the aspects pertaining to the diversity of elements within the alliance portfolio with which a firm must interact) to innovation performance and found an inverse U-shape. Grimpe and Kaiser (2010) choose to relate innovation performance with one specific type of knowledge acquisition, which is R&D outsourcing and found a similar result, an inverted U-shaped relationship. Other papers also found an inverted U-shape relationship between *R&D Collaboration* and collaboration with suppliers and competitors (Kang & Kang, 2010), partners' technological relatedness (Petruzzelli, 2011), explorative technological activities (Rene Belderbos, Faems, Leten, & Van Looy, 2010). So, what we can notice is that to a certain point there is a positive impact on performance related to *R&D Collaboration*. However, a myriad of factors influences this relation.

Considering the top 25 papers from our data, the majority of the methodology used surveys at the firm level. While this brings very interesting insights to enhance the understanding of this complex relationship between *R&D Collaboration* and *Performance*, it does not provide finer grained evidence of the project execution elements.

2.1.1. *The type of partner and R&D Collaboration*

The type of partners in R&D collaboration is a common concern as an effective selection of partners is recognized as being a core factor affecting collaboration performance (Ireland, Hitt, & Vaidyanath, 2002). Studies show that diverse types of partners have a different influence on *Performance*. Kang and Kang(2010) show that *R&D Collaboration* with customers and universities have a positive effect on product innovation whereas *R&D Collaboration* with suppliers and competitors have an inverted-U shape relationship with product innovation. Un, Cuervo-Cazurra, and Asakawa (2010) found that *R&D Collaboration* with suppliers have the

highest positive impact on product innovation, followed by *Collaboration* with universities. Aschhoff and Schmidt (2008) found that *R&D Cooperation* with competitors leads to greater cost reductions that are attributable to innovative processes, and *R&D Cooperation* with research institutes has a positive influence on a firm's economic success with market innovations. Belderbos, Carree, and Lokshin (2006) found that customer cooperation helps to increase market acceptance and the diffusion of product innovations and enhances the impact of competitor and university cooperation, suggesting that a joint adoption of cooperation strategies could be beneficial to company performance, depending on the firm's size and specific strategy combinations. In a previous paper these authors showed that competitor and supplier cooperation focus on incremental innovation, improving the productivity performance of firms, and that customers and universities are important sources of knowledge for firms pursuing radical innovations (René Belderbos, Carree, & Lokshin, 2004). Considering the type of partner perspective, Du et al. (2014) investigated whether project management formality could have diverse impacts according to whether the partner type was Science-based or Market-based and showed that the financial performance of the project is influenced by the way the project is managed with diverse results by partner type. Also, at the project level, Schwartz, Peglow, Fritsch, & Guenther (2012) found that the project performance measures have diverse results by type of partner and show that university involvement has a positive effect on project innovation output in terms of the number of publications but not in terms of patent application. Conversely, large firm involvement is strongly positively related to the number of patent applications, but not to the number of publications. Therefore, it is not only the partner type that influences *Performance* as there are other variables related to the partner type that should be better understood in order to enhance the *Performance* of collaborative projects. This contingent view in collaborative projects is in its infancy but is growing fast (Gesing, Antons, Piening, Rese, & Salge, 2015).

2.1.2. *Alliance characteristics and R&D Collaboration*

The characteristics of the *Alliance* also show some influence on *Performance* and appeared in the data related to *R&D Collaboration*. Despite the vast attention devoted to strategic alliances, some important insights are also provided by a portfolio view—an approach that is in its infancy (Duysters & Lokshin, 2011). There is a long tradition in

strategic alliance literature that will not be explored here as the focus is to work on the data provided by our search protocol described at the beginning of the section.

Sampson (2007) found that a hierarchical organization such as an equity joint venture improves a firm's benefits from alliances with high levels of technological diversity and that the alliance organizational form influences partner ability and incentives to share information, which improves performance. R&D alliances were found to be the most suitable forms to help create new technologies (Lin, Wu, Chang, Wang, & Lee, 2012), and the performance peak is achieved at a moderate technological distance as information transfer and learning are key benefits of R&D alliances. Duysters & Lokshin (2011) state that from both the individual alliance perspective and the portfolio approach. They provide evidence that more innovative firms tend to have alliance portfolios which are broader in terms of different types of alliance partners and skewed towards foreign partners and there is a need for more studies regarding this portfolio view, including new dimensions to the portfolio like degrees of competition and industry differences. Another interesting avenue for further research is the impact of structural properties of alliance networks on a firm's innovative output, which includes, for example, discussions related to over-embeddedness.

2.1.3. *Company characteristics and R&D Collaboration*

Although the structural antecedents of firms such as R&D capability and social embeddedness do not guarantee high-performing collaborative innovation (Davis & Eisenhardt, 2011), some relations between a firm's characteristics and innovation performance have been identified. A very common issue is R&D intensity. Influenced by Cohen and Lenvithal's (1990) seminal paper, the literature recognizes the importance of internal R&D investment to leverage collaborative R&D results. Kuen-Hung and Wang (2009) and Lin et al. (2012) show that by collaborating with different types of partners, firms with more internal R&D investments gain higher innovation returns than those with fewer such activities. There is a challenge to balance internal and external R&D and specifically combine diverse types of external R&D and complementarities with internal ones (Schmiedeberg, 2008) to achieve the highest performance potential.

2.1.4 *Project execution issues and R&D Collaboration*

Some studies which are more directly related to project execution provide evidence of what can improve the collaborative project results. Davis and Eisenhardt (2011) show that high-performing collaborative innovation is associated with the leadership roles of the collaboration partner in solving critical innovation problems related to recombination across boundaries. He suggests that dominating and consensus leadership processes are associated with less innovation, but a rotating leadership is associated with more innovation. Other variables focusing on achieving project execution success have been studied. Baba, Shichijo, and Sedita, (2009) studied the university-industry relation and specifically considered two types of scientists, showing that scientists that have the ability to communicate with firms and to be oriented towards the commercialization of scientific discoveries (Pasteur Scientist) can increase firms' R&D productivity. This "scientist type" can contribute as a "boundary spanner in charge of combining their Science-based background with the knowledge, mainly ingrained into practice and trial-and-error procedures, of corporate researchers" (Baba et al., 2009, p. 763).

2.1.5 *Geographical distance, Previous links, R&D intensity and R&D Collaboration*

Other variables were also identified in our data. *Geographical distance* and *prior ties* in R&D industry-university collaboration were positively related to the achievement of higher innovative outcomes (Petruzzelli, 2011). Although no other study found an effect of spatial distance and prior ties on performance (Schwartz et al., 2012), temporal dynamics seem to also influence the relation (which can help us to understand these diverse findings), where persistent collaboration is that which has a systematically positive effect on innovativeness (René Belderbos, Carree, Lokshin, & Sastre, 2014). These authors explain that with the exception of recently formed collaboration with universities and research institutes, other temporal patterns of collaboration do not significantly improve innovation performance. In terms of *Geographical distance*, *R&D intensity* was found to have a moderate role in collaborating with geographically distant partners, where remote collaboration is positively related with innovation performance, but at low R&D intensity this relation vanishes (Berchicci, 2011).

2.1.6 Governance mechanisms and R&D Collaboration

Governance mechanisms are one important variable that influences innovation outcomes. The choice of a particular form of governance seems not just to influence the transaction cost of collaborative project but also the behavior of the partners, for example, opportunistic behavior, trust, and willingness to share knowledge. A current discussion related to *governance mechanisms* in collaborative innovation projects is to understand whether there are more suitable mechanisms for a certain type of project, considering for example *Partner type* and *Innovation objectives* (Gesing et al., 2015). While informal modes rely on self-enforcing mechanisms such as trust and reciprocity, formal ones use well-specified contracts that may reduce uncertainty risk and enhance coordination activities. Recent findings have revealed that the positive payoff from innovation collaboration with business customer and universities varies as a function of the specific governance mode used (Gesing et al., 2015), reinforcing a contingent perspective of collaboration with external partners. “Formal, contractual governance mechanism, turned out to be more effective than informal, self-enforcing mechanisms in enhancing firms’ return not only from market-focused collaboration, but remarkably also from science-focused collaboration. Informal, relational governance, in contrast, emerged as being more effective than formal, contractual governance in safeguarding the focal firm from possible negative interaction effects between external collaboration and internal R&D” (Gesing et al., 2015, p. 435). Specifically, for trust-based governance, in contracts with a universalistic view of trust, Carson, Madhok, Varman, and John (2003) posit that the performance is contingent on the ability of the partners to “read” each other and learn about their counterparts’ behavior. They found that trust-based governance has a large positive impact on task performance when the client is more skilled at understanding the task at hand. As information-processing abilities increase, firms adopt trust-based governance to a greater extent. In formal governance mechanisms, while there is evidence that intellectual property rights generally work well in moderating the relation between R&D cooperation and imitation, contracts do not.

This section reviewed the literature on *R&D Collaboration* and *Performance*, showing the main variables that are studied regarding this relation. They are summarized in the following table (Table 2.1), which may provide a starting point for future studies.

Table 2.1: Variables identified on *R&D Collaboration and Performance* literature

Variable	Authors
Alliance Portfolio	Duysters and Lokshin,(2011); Rene Belderbos, Gilsing, & Suzuki,(2016).
Geographic distance	Petruzzelli, (2011); Berchicci, de Jong and Freel, (2016); Belderbos, Carree, Diederer, Lokshin and Veugelers, (2004).
Governance mechanisms	Barbic, Hidalgo and Cagliano, (2016); Belderbos et al. (2014); Belderbos, Cassiman, Faems, Leten and Looy, (2014); Veer, Lorenz and Blind, (2016); Frankort, (2013); Kyoung-Joo, (2011); Faems, Janssens, and van Looy,(2007); Melander and Lakemond, (2015); Gesing et al.,(2015); Arranz and de Arroyabe, (2007); Carson et al., (2003); Davenport, Davies, and Grimes, (1999); Wu, Wang, and Chen, (2017).
Leadership	Jeong and Choi, (2015); Davis and Eisenhardt, (2011).
Partner and/or firm characteristics	Gesing et al., (2015); Hottenrott and Lopes-Bento, (2016); Geum, Lee, Yoon and Park, (2013); Lokshin, Hagedoorn, & Letterie, (2011); Belderbos, Carree, Diederer, et al., (2004); Trott and Simms, (2017); Belderbos et al.,(2016); Barzi, Cortelezzi, Marseguerra, and Zoia, (2015); Hemmert, (2004); Schwartz et al., (2012).
Project management	Du, Leten and Vanhaverbeke, (2014).
Previous Link	Belderbos, Carree, et al., (2014); Bruneel, D'Este and Salter, (2010).
R&D intensity	Berchicci et al., (2016); Belderbos, Carree, Diederer, et al., (2004); Sofka and Grimpe, (2010).
Technology diversity	Sampson, (2007); Lin et al., (2012); Petruzzelli, 2011; von Raesfeld, Geurts, Jansen, Boshuizen, and Luttge, (2012).
Type of partner / Knowledge source	Du, Leten and Vanhaverbeke (2014); Du, Leten, Vanhaverbeke and Lopez-vega, (2014); Chen, Vanhaverbeke and Du (2016); Geum et al., (2013); Belderbos, Cassiman, et al., (2014); Noseleit and de Faria, (2013); Kang and Kang, (2010); Belderbos, Carree, et al., (2014); Belderbos, Carree, Diederer, et al., (2004); Belderbos, Carree, and Lokshin, (2004); Chen et al.,(2016); Frenz & Ietto-Gillies,(2009); Berchicci, (2011); Huang and Yu, (2011); Estrada, Faems, Martin, and Perez,(2016).

Source: Elaborated by the Author

2.2 Project Management in collaborative R&D projects

As previous section showed, little has been written on collaborative R&D projects that relate *Project Management* and *Performance*. Actually, to our knowledge, only the study from Du, Leten, & Vanhaverbeke (2014) establishes the relationship between these variables (we also analyzed 28 papers that cite Du, Leten, & Vanhaverbeke (2014) work, and none of them made the relationship with performance and project management issues).

To identify studies on *R&D Collaborative projects* and *Project Management* (not focusing on *Performance*), a search on the Web of Science data base with the following protocol was made:

- (i) Topic: *Collaborative R&D Project + Collaborative Research Project*
- (ii) Area: Business and Management
- (iii) Type: Article (92 papers)
- (iv) The abstracts were read and those that have *Project Management* as part of the study were considered.

During the review of the papers a literature review of *Project Management* literature related to *Collaborative Research Projects* (vom Brocke & Lippe, 2015) was found. Papers presented in this review that were not part of the data from Web of Science search were also considered. Table 2.2 presents the main issues discussed in both forms of data.

Table 2.2 – Collaborative R&D project literature by main issue

Main issue	Type of study	Authors
Contingent Project Management Approach	Thematic analysis Survey	Lippe and vom Brocke, (2016); Du et al,(2014) Kim and Lee (2003).
Leadership	Case study	Mailhot, Gagnon, Langley, and Binette, (2016);

Table 2.2: Collaborative R&D project literature by main issue - Continued

Main issue	Type of study	Authors
Success factors	Survey	Littler, Leverick, and Bruce, (1995); Wu et al., (2017)
	Case Study	Barnes, Pashby and Gibbons, (2002); Barnes, Pashby and Gibbons, (2006); Calamel, Defélix, Picq and Retour, (2012) ;
Coordination and control of R&D collaborative activities	Case study	Morandi, (2013); Bjerregaard, (2010).
Dynamic Process of collaboration	Case study	Calamel et al., (2012).
Determinants of performance in Collaborative R&D projects	Case study	Grimaldi and von Tunzelmann, (2002, 2003).
Challenges in collaborative R&D projects	Case study	Ruuska and Teigland, (2009).
	Literature Review	vom Brocke and Lippe, (2015).
Managing creative tasks in collaborative research projects	Case study	vom Brocke and Lippe, (2013)

Source: Elaborated by the Author

The literature recognizes that *collaborative Projects* face many challenges that a general *Project Management Approach* does not support (Du, Leten, & Vanhaverbeke, 2014; Y. Kim & Lee, 2003; Lippe & vom Brocke, 2016; vom Brocke & Lippe, 2015). However, it also recognizes that *Collaboration in Innovation Projects* has to be constructed and encouraged. To succeed, the key lies in the way it is managed, including knowing differences between project phases (Calamel et al., 2012). Previous studies identified some general challenges in *Collaborative R&D Projects*, and concerns are usually related to coordinating divergent management styles (Littler et al., 1995; vom Brocke & Lippe, 2015), the budgeting process of collaborating firms (Littler et al., 1995), partner heterogeneity and dissimilarities (Barnes et al., 2002, 2006; Estrada, Faems, Martin Cruz, et al., 2016; vom Brocke & Lippe, 2015), complementary aims and complementary expertise, the existence of a hidden agenda, commitment, trust between partners, continuity of personnel, corporate stability (Barnes et al., 2002, 2006), multiple and contradictory stakeholders expectations, the role and skill set of the project manager (Mailhot et al., 2016; Ruuska & Teigland, 2009; vom Brocke & Lippe, 2015).

Barnes et al. (2002, 2006), conducting a multi-case study, identified some success factors and organized them into categories (see Figure 2.8). Barnes et al. (2006) argue that while research on university-industry collaboration has concentrated primarily on the “cultural gaps”, they confirm previous research that suggested the existence of an overlap between management factors affecting the success in both industry-industry and university-industry relationships (recent research emphasizes that a contingent approach to the type of partner should be considered — this will also be discussed in this section). The area where the greatest number of success factors were identified was *Project Management* (Barnes et al., 2002), on which we concentrate due to our research objective. The project management success factors that were identified in the literature were: (i) clear definition of objectives; (i) clearly defined responsibilities; (iii) mutually agreed project plan; (iv) realistic aims; (v) adequate resources; (vi) defined project milestones; (vii) regular progress monitoring; (viii) effective communication; (ix) ensuring collaborator delivery. These authors also noticed that

“while these management factors are essentially generic and all-pervading, certain factors will necessary prove more critical in some type of collaboration than others, as a result of very different purposes, circumstances and characteristics of each type” (Barnes et al., 2006, p. 397).

Figure 2.8: The good practice model incorporating university-industry factors

Source: Barnes et al (2006)

As Clark and Wheelwright (1993) state, an individual project is part of a broader strategy and direction of the organization. At the front end of a project, the firm needs a process to connect it to the overall strategy. “An important part of this connections is the establishment of clear, measurable goals that can guide development and ensure the projects contribution to overall development objectives” (Clark & Wheelwright, 1993, p. 2183). With this, project leaders have a much clearer sense of mission and purpose. This clarity simplifies the project and focuses the actual work of development. These authors’ focus was not on a collaborative project with an external partner, but when we consider that an individual project is part of the whole of a company plan and the importance of being clearly connected to this broader strategy, it is easier to realize that different organizations might have diverse strategies, objectives, identities and missions which enhance the complexity of the project planning and execution in a collaborative project. Despite having these organizational differences, each partner should know how this individual project is connected to its organization's overall strategy and be sure that the expected objectives for the collaborative project are aligned to it. Bearing this in mind, a clear and common agreed definition of objectives, responsibilities and the whole project set-up has been shown to have “a positive influence on the involvement and commitment of partners within a collaborative project” (Barnes et al., 2002, p. 399). Morandi (2013), in a qualitative study, reinforces this perspective. She identified key issues in collaborative R&D projects related to coordination systems and summarizes her findings as follows:

“[...] regardless of the features of the project and partnerships, initially partners should devote themselves to planning activities more than they do for internal R&D processes. This safeguards them from misunderstandings during the project evolution due to the misalignment of partners’ objectives and the low commitment of partners. Planning efforts aim to create a common perspective regarding the research project. They are particularly needed in industry-university agreements because these agreements are usually affected by a high difference in partners’ cultural backgrounds.” (Morandi, 2013, p. 88).

Going forward through understanding the “black box” of collaborative R&D projects, Mailhot et al., (2016) focused on the leadership issue, but going beyond the human factor. While most studies in collaborative R&D project management focus on planning issues to guarantee a shared vision, they observed how “various kinds of objects (including material artefacts, more abstract concepts and human-material assemblages such as committees and procedures) came to participate in and contribute to the practices of individual leaders, connecting different

worlds, and enabling the enactment of leadership roles” (Mailhot et al., 2016, p. 55). Their findings suggest that “a distributed structure of leadership throughout the project allowed the different actors involved to pursue the same course without having to share the same worldviews or interests” (Mailhot et al., 2016, p. 81). Here they emphasize the importance of leaders playing different roles to translate the project to each group that needs to be mobilized and suggest that the leadership practices during the project are an important source to add flexibility in terms of promoting adjustments in the project and facilitate communication.

The *Project Management* factors presented in the Barnes et al. (2006) practice model for collaboration are no different from those that are part of traditional project management. Clark and Wheelwright (1993) defined the following *Project Management* dimensions: Project definition; Project organization and staffing; Project management leadership; Problem solving, testing and prototyping; Senior management review and control; Real-time/mid-course corrections. *Project Management* literature is a well-established area, but the collaborative project perspective emphasizes specific factors that should receive greater attention due to their importance for the characteristics and complexity of a collaborative R&D project (Morandi, 2013). Clark and Wheelwright (1993, p. 2813) noticed that “there may be several different “models” and “approaches” that the firm may develop to apply to different kind of projects”. They already suggested that product and process innovation projects should be differently managed according to their alliance nature. Also, according to their degree of innovation: whether they are derivative, platform or breakthrough projects.

While general challenges and success factors have been identified, there is also the perception that these factors do not fit all collaborative projects in the same way. A contingent perspective in *Collaborative R&D Projects*, a small but rapidly growing literature stream, seeks to explain the relationship of diverse variables (internal and external to the firm) to *Performance* (Gesing et al., 2015) (previous section). However, though the literature also recognizes that this perspective is suitable for *Project Management* in *Collaborative R&D Projects* (Barnes, Pashby, & Gibbons, 2006; Calamel, Defélix, Picq, & Retour, 2012), there are, to our knowledge, very few studies regarding this issue. Recently, Lippe and Brocke (2016) have argued that due to ambiguously defined goals and the heterogeneous interest of many partners, a situation-specific approach should be used. Their proposal involves establishing situation profiles as a concept to relate each situation to a management method that corresponds to its managerial needs. The findings of Kim and Lee (2003) suggest that the different contingencies

bring about different patterns of collaborative projects, “which in turn lead to a different set of success factors, since different information, roles of partners and the focal firm, and collaboration management practices are needed to successfully implement the different types of projects” (Y. Kim & Lee, 2003, p. 59). Du et al. (2014), in a quantitative study, provide very strong evidence that the type of project management used influences project performance in diverse ways by partner type. Their survey focused on three project management activities where a higher score implies that a project is managed in a more formal way with regular project reviews and strict control to make sure the projects proceed according to their project plan. The results indicate that formality in *Project Management* has a positive impact on the financial performance of projects that are developed with a Market-based partner but not with a Science-based partner. This paper reinforces the need for a contingent approach to the *Project Management* of collaborative R&D projects, especially for projects that rely on Science-based partnerships.

2.3 Knowledge sources and collaboration

Behind the development of R&D projects in collaboration with external partners lies the assumption that knowledge diversity enhances the innovation potential (Faems et al., 2005). The literature supports this view but adds some constraints (Du, Leten, & Vanhaverbeke, 2014; Laursen & Salter, 2006). In terms of knowledge sources, it is known that there is a diverse impact on innovation according to the type of partner. For example, incremental innovation in partnerships with Market-based partners and radical innovation with Science-based ones are expected results (Belderbos, Carree, et al., 2014). It is also recognized that the challenges in managing partnerships are not the same with different types of knowledge sources (Mora-Valentin et al., 2004). This section, will explore the findings the literature brings to help our understanding of the characteristics of these different knowledge sources and their collaboration challenges.

The challenges in managing external relationships for innovation are associated with inter-partner dissimilarities presented in external relationships, which are differences in partners' organizational attributes (Parkhe, 1991). These dissimilarities can be categorized as

routine-based dissimilarities and orientation-based dissimilarities² (Estrada, Faems, Martin Cruz, et al., 2016). The first is related to patterns and behavior that describe how an organization operates and interacts with its partner. The second implies that partners have different alliance goals and expectations. Focusing on identifying how to overcome interaction barriers, Bruneel et al. (2010) suggest that University – Industry [UI] relationships have both transaction-related barriers and orientation-related ones. These transaction-related barriers are related to conflicts over IP and dealing with university administration. Knowing that challenges are related to dissimilarities, it is important to know what is different between types of knowledge sources.

First, let's clarify what these knowledge sources are. A partnership in an R&D project can be developed with universities, research labs, suppliers, competitors, customers and other companies or individual actors like consultants. Prior research classified external knowledge sources into two major types: Science-based (scientific knowledge e.g. university, research institutions) and Market-based (industrial knowledge e.g. customers and suppliers) (Du, Leten, & Vanhaverbeke, 2014). Other research adds competitors, specialist knowledge providers and suggests another type of classification: Science-based knowledge sources (e.g. universities and research labs), knowledge sources in the value chain (e.g. suppliers and customers), other market-related knowledge sources (e.g. competitors and companies in other industries), and technology service providers (e.g. innomediaries) (Chen et al., 2016). In both studies, there is a general assumption that Market-based knowledge sources involve for-profit institutions which aim to develop successful products in competitive markets. Science-based knowledge sources involve institutions focused on generating and disseminating scientific knowledge. Literature provides diverse ways of grouping the sources. The level of grouping depends on the type of heterogeneity that one wants to explore. Considering that the literature usually explores the University-Industry relation to identify the main differences, we rely on this relation as a proxy for Science-based groups.

Distinguishing the type of knowledge also brings other types of differences between the sources. They have different missions and goals, but also routines, resources, and time horizon (Estrada, Faems, Martin Cruz, et al., 2016). There is a different institutional logic, which is

² Estrada, Faems, Martin, et al., 2016 used this classification following previous studies in interfirm alliances. See their work for more explanation of other classifications.

often considered a “cultural gap”. The focus of firms in the process of knowledge creation is the appropriation of knowledge for private gain, and openness to external actors is a strategic mechanism to gain advantage over competitors (Bruneel et al., 2010; Dasgupta & David, 1994). On the other hand, scientific institutions rely on helping to build reliable and public knowledge, which is central to the growth of the university to develop a reputation for academic success and career sustainability (Bruneel et al., 2010). Academic science is constituted around four institutional norms, which are rooted in Mertonian norms: communalism, universalism, disinterestedness and organized skepticism (Merton, 1942, 1973). These norms are the core to guide academics in the way to perform their work. Academic research puts this into practice by relying on a blind peer review system and resource allocation principles based upon publications and citations (Bjerregaard, 2010). Bruneel et al. (2010) emphasize that while it is recognized that the university has a long-term orientation, which they call ‘classic barrier’ to university-industry collaboration, other factors are important in constraining the UI relationship, like those related to intellectual property, administrative procedures, research and university orientation, attitudes and behavior of university administration, and the Technology Transfer Office. These authors found that orientation-based barriers are lower than transaction-based ones.

Some dissimilarities between Science-based and Market-based knowledge sources are summarized in Table 2.3.

Table 2.3 - Some dissimilarities between Market-based and Science-based sources

	Market-based source	Science-based source	Source
Mission	Develop successful products (private)	Disseminate scientific knowledge (public)	Estrada et al., 2016
Goal	Profit	Enhance knowledge	Bruneel et al., 2010
Horizon	As short as possible	Long-term	Bruneel et al., 2010
Reward system	Based on product launch (profit, commercialization)	Based on publications and citations Intellectual Property	Bjerregaard, 2010 Bruneel et al., 2010
Resource allocation	Based on company strategy to be competitive	Based on publications and citations	Bjerregaard, 2010

Source: Elaborated by the Authors

This table bring a very well-known view regarding the institutional characteristics of these sources. However, changes are taking place, and dissimilarities are being reduced

(Bjerregaard, 2010). Due to the increase in the UI relationship, universities are adopting a new approach, not related exclusively to teaching and research. This is entrepreneur science, which brings normative changes in science (Etzkowitz, 1998). While the traditional norms of science condemn profit-making motives, a growing number of scientific fields open up possibilities for scientists to simultaneously fulfil two goals: the pursuit of truth and profit-making (Etzkowitz, 1998). The development of this new role may help to converge the logics of these knowledge sources that facilitate the collaboration process. As far as companies are concerned, it is being shown that they are going through a ‘scientification’ by adopting ‘open science’ norms similar to those governing R&D behavior in universities (Bjerregaard, 2010). What motivates this is the expectation of accessing the scientific network, increasing the possibility of recruiting and retaining highly qualified researchers and build a reputation to facilitate the establishment of new collaboration. These findings suggest that

“factors pertaining to hybrid knowledge exchange, high cross-sector researcher mobility and university researchers’ accommodation to entrepreneurial norms may blur the formerly more discrete and defended institutional boundaries of academia and industry” (Bjerregaard, 2010, p. 106).

While some convergence can benefit collaboration, great dissimilarities between sources are evident. How to overcome the challenges that the dissimilarities bring is a current concern in the literature as collaboration does not seem to have been reduced over the years (Chesbrough, 2017).

2.3.1 Overcoming knowledge source dissimilarity challenges in collaborative projects

As discussed previously, the literature on *Collaborative Project Management* found evidence that project management formality influences project performance differently accordingly to the knowledge source type (Du, Leten, & Vanhaverbeke, 2014). This evidence was very influential in this study as it motivated us to go deeper into *Project Management* success factors and look for more fine-grained information of what should be different in *Project Management* in projects made in collaboration with different type of knowledge sources. However, while *Project Management* literature in *Collaborative Projects* does present success factors in *R&D Collaborative Project Management* (Barnes et al., 2006) and is aware of challenges resulting from inter-cultural, inter-organizational and inter-disciplinary

management (vom Brocke & Lippe, 2015), it does not integrate its findings into other research streams that could help to discuss the effectiveness of the use (or not or even some modification on the way it is used) of some project management success factors, more specifically by knowledge type.

Vom Brocke and Lippe (2015) presented a guideline to overcome challenges related to managing research collaboration with heterogeneous project partners, summarized in Table 4. These guidelines do not make any distinction between types of sources and are a general list to be aware of when working on projects with heterogeneous partners.

Table 2.4: Summary of guidelines to overcome challenges with heterogeneous project partners

Challenge and authors	Guideline for Project Management
Diversity of individuals.	<ul style="list-style-type: none"> • Take cultural compatibility into account when selecting partners. • Take previous work relationships into account when selecting partners. • Provide training in collaborative work and inter-cultural awareness.
Adler, Elmquist, & Norrgren, 2009; Barnes et al., 2002, 2006; Calamel et al., 2012; Ruuska & Teigland, 2009	<ul style="list-style-type: none"> • Foster translation between the disciplines involved and support differing ways of managing knowledge. • Conduct joint problem-solving tasks to facilitate collective competence. • Make clear decisions on when to work disciplinarily and when to integrate different results and manage work accordingly. • Ensure the staff's understanding of the "big picture" through continuous open and balanced communication, and plan sufficient time at project start to convey objectives to all project members. • Performance measurement should include evaluating the collaboration spirit and work mode, in addition to the project outcome. • Build mutual trust relationships between individuals.
Multiple, contradictory stakeholders' expectations	<ul style="list-style-type: none"> • Select partners who share a strategic interest in the research and who are willing to fulfil their intended roles. • Leadership team instead of a single project manager to account for multi-stakeholder views and expectations. • Co-develop project charter: define mutually agreed objectives based on established areas of common interest and mutual benefit to reduce misinterpretations; tie-in objectives as early as possible. • Discuss and harmonise expectations; create awareness of sources of conflicts. • Define clear roles and responsibilities of all parties involved. • Treat project partners as equally as possible.
Geografic distance of project staff	<ul style="list-style-type: none"> • Develop a clear communication strategy that includes "consideration of the forms of written communication to be used, incorporating different types of written report for different purposes, or to be delivered at different stages in the collaboration" (Barnes et al., 2002, p. 278). • Maintain strong informal communications with specific guidelines, such as avoiding reporting of unnecessary or poor-quality information. • Foster face-to-face meetings and opportunities for longer periods of working together. • Power distance, uncertainty avoidance, and individualism should be considered relevant cultural factors when assigning work to locations. <p>Guidelines</p>

Source: Elaborated by the Author

Following broader literature on interorganizational collaboration, a core premise is that inter-partner dissimilarities can be detrimental to collaboration because they are likely to disrupt coordination and cooperation processes³. This literature brings an interesting discussion related to the interdependence of these two processes (Gulati, Wohlgezogen, & Zhelyazkov, 2012) and also brings some prescriptions to face challenges related to them in collaboration relationships. In a joint analysis of the two types of dissimilarities in University-Industry collaboration, Estrada et al. (2016) suggested that having both types (orientation-based and routine-based) in the same alliance impacts negatively on the alliance. However, if orientation-based⁴ is not present, it enhances the chances of success:

“[...] in the absence of orientation-based dissimilarities, firms and Research Organizations seem to be more able to attenuate their routine-based dissimilarities through fruitful joint sensemaking, which in turn facilitates coordination and cooperation processes increasing the likelihood of successful outcomes in IU alliances.” (Estrada, Faems, Martin, et al., 2016, p. 2020)

Bruneel et al. (2010) found that orientation-based⁵ barriers can be overcome as attitudinal issues are influenced by learning through experience, but transactional-related barriers may continue even in repeated and multiple collaborations.

“These results suggest that routines learnt through conducting joint research with universities lower the barriers related to the basic and long-term nature of university research, helping to overcome attitudinal differences between the partners on research methods and targets. However, experience of working with universities does not lower the perceived barriers related to university administrative procedures and conflicts over IP” (Bruneel et al., 2010, p. 864).

³ Coordination is the “adjustment of partners’ actions to achieve jointly determined goals”, whereas cooperation refers to “joint pursuit of agreed-on goal(s) in a manner corresponding to a shared understanding about contributions and payoffs” (Gulati et al., 2012).

⁴ These authors considered orientation-based as: alliance rationale, reciprocal obligation, alliance scope and horizon.

⁵ These authors considered orientation-based related to the following assumptions: ‘university research is extremely orientated towards pure science’; ‘long-term orientation of university research (concerns over lower sense of urgency of university researchers compared to industry researchers)’; and ‘mutual lack of understanding about expectations and working practices’.

As this transaction-related barrier is more difficult to overcome, Bruneel et al. (2010) suggest that investing in ex-ante IP agreements might avoid follow-on conflicts over the distribution of the rewards of a project. However, they also suggest finding simple mechanisms for managing UI relationships such as adding governance policy efforts and note that university administration rules can increase transaction-related barriers.

Bjerregaard's (2010) findings bring some suggestions to overcome UI barriers related to different institutional logics. Factors like high cross-sector researcher mobility, university acceptance of entrepreneurial norms, and hybrid knowledge exchange may reduce the formerly more discrete boundaries between academia and industry, confirming previous research.

Estrada et al. (2016) emphasize the need to be aware of the fact that “even when the project seems very promising, firms and research organizations might possess orientation-based dissimilarities, implying divergent beliefs on key questions such as ‘why *we* collaborate’” (Estrada, Faems, Martin, et al., 2016, p. 2020). They suggest that in order to avoid future problems in coordination and collaboration “partners in IU collaboration should conduct an early diagnosis of their dissimilarities to timely learn *about* each other, determining their ability to learn *from* each other” (Estrada, Faems, Martin, et al., 2016, p. 2020).

Project Management Success Factors in Collaborative R&D projects (Barnes et al., 2006) seem to embrace some of these coordination and cooperation concerns related to dissimilarities. However, it adds a focus on the project management level. More specifically, the PMSFs emphasizes the need to be clear in the definition of objectives and responsibilities and to develop mutually agreed plans to positively influence the involvement and commitment of partners within a *Collaborative Project*. However, Estrada et al. (2016) stress the need for a deep understanding not only of the project but also of the parties involved as dissimilarities could influence the ability to learn from each other, which can have a greater impact after the “honeymoon” period.

Another literature stream focusing on knowledge boundaries has sought to understand knowledge exchange conditions and how knowledge boundaries can be spanned, and an efficient collaboration created. For this thesis, as knowledge boundaries have been identified to be at the core of inter-organizational *R&D Collaboration* challenges (Smith, 2016), they should be considered in our discussion on how to overcome dissimilarities in collaborative projects. This stream relies on the assumption that there are different perceptions of reality which bring

different interpretations of shared communication and language. Knowing this, the literature suggests that in order to improve innovation it is necessary to deal explicitly with interpretative barriers (Dougherty, 1992). In this regard, knowledge boundaries were investigated in diverse streams: thought worlds and interpretive schemes; willingness to share knowledge; social identity and collaboration; knowledge boundaries and novelty; and the relationships between different knowledge boundaries⁶. As concluded by Smith (2016), multiple boundary types may exist in a project and are highly contextual as different tasks or practices determine which boundary emerge, as shown in Figure 2.9.

“Being knowledgeable that some boundaries are more dominant in relation to certain tasks and activities, and other boundaries in relation to others, the project manager may be particularly alert toward these boundaries when the team is working on a given task or activity” (Smith, 2016, p. 65).

Figure 2.9: Knowledge boundaries in inter-organizational R&D

Source: Smith, 2016, p. 65

In highly innovative inter-organizational R&D projects managers can help to reduce the boundaries by coordinating uncertainty reduction in the team, which means ensuring that different participating organizations should agree on a shared direction, and this might diminish ambiguity in the interpretation of team members, and give participating employees some level

⁶ See Smith (2016) paper to have a more detailed description of each research stream.

of autonomy to free team members from constraints imposed by their employing organizations (Smith, 2016).

In terms of the literature presented in this section and the project management success factors presented by Barnes et al. (2006), when possible, we classified the guidelines to overcome the challenges according to each success factor. Table 2.5 presents these guidelines. As specific guidelines for the factors such as realistic aims, adequate resources and project milestone were not identified, they were grouped into a general factor called *Workplan*.

Table 2.5: Guidelines for Collaborative Project Management by success factor

Success factor in collaborative project management	Guidelines
Clearly defined objective	Co-develop project charter: define mutually agreed objectives based on established areas of common interest and mutual benefit to reduce misinterpretations; tie-in objectives as early as possible. Ensuring that different participating organizations agree on a shared direction (Smith, 2016)
Clearly defined responsibilities	Define clear roles and responsibilities of all parties involved (vom Brocke & Lippe, 2015). Ensuring that different participating organizations agree on a shared direction (Smith, 2016)
Mutually agreed project plans	Plan sufficient time at project start to convey objectives to all project members.(vom Brocke & Lippe, 2015) Ensuring that different participating organizations agree on a shared direction (Smith, 2016)
Workplan	Ensuring that different participating organizations agree on a shared direction (Smith, 2016)
Simple collaboration agreement	Investing in ex-ant IP agreement might avoid follow-on conflicts over the distribution of rewards of a project (Bruneel et al., 2010)
Regular progress monitoring	Performance measurement should include evaluating the collaboration spirit and work mode, in addition to the project outcome. (vom Brocke & Lippe, 2015) Leave participating employees with some level of autonomy (Smith, 2016)

Source: Elaborated by the Author

Table 2.5 - Guidelines for Collaborative Project Management by success factor - Continued

Success factor in collaborative project management	Guidelines
Effective communication	<p>Provide training in collaborative work and inter-cultural awareness (Calamel et al., 2012)</p> <p>Foster translation between the disciplines involved and support differing ways of managing knowledge (vom Brocke & Lippe, 2015).</p> <p>Conduct joint problem-solving tasks to facilitate collective competence (vom Brocke & Lippe, 2015).</p> <p>Ensure the staff's understanding of the “big picture” through continuous open and balanced communication (vom Brocke & Lippe, 2015)..</p> <p>Develop a clear communication strategy that includes “consideration of the forms of written communication to be used, incorporating different types of written report for different purposes, or to be delivered at different stages in the collaboration” (Barnes et al., 2002, p. 278).</p> <p>Maintain strong informal communications with specific guidelines, such as avoiding reporting of unnecessary or poor-quality information (vom Brocke & Lippe, 2015).</p> <p>Foster face-to-face meetings and opportunities for longer periods of working together(vom Brocke & Lippe, 2015).</p> <p>Cross-sector researcher mobility, university accommodation to entrepreneurial norms and hybrid knowledge exchange (Bjerregaard, 2010)</p> <p>Discuss and harmonize expectations; create awareness of sources of conflicts (vom Brocke & Lippe, 2015)..</p>

Source: Elaborated by the Author

These guidelines are very general and are not classified into specific types of projects, partners and other contextual factors. However, they can be used as a starting point to move forward in a more contingent way and can help to enrich our discussion of knowledge sources and project management success factors.

3. R&D PROJECT PERFORMANCE MEASURES

Performance measures are defined as the metrics used to quantify the efficiency and effectiveness of action (Neely, Mills, Platts, Gregory, & Richards, 1996). The selection of suitable measures for the right areas of measurement is one of the most essential issues affecting the usefulness of measures in practical management (Henttonen, Ojanen, & Puumalainen, 2016). Research on *Performance Measures* in R&D has gained interest since seminal publications in this regard were produced during the 1980s and 1990s. Since then, research has been examining the challenges of measuring R&D that are related to (i) being too subjective, (ii) being too complicated; (iii) having too much focus on behavior; and (iv) having too much emphasis on internal measurement (Ojanen & Vuola, 2006). It is now generally accepted that different factors influence the selection of measures to evaluate *R&D Performance*. Some of them, categorized as measurement dimensions, are the following (Table 6): the purpose of R&D performance analysis, the level of R&D performance analysis, the type of R&D to be evaluated, and the phase of the R&D process to be measured (Ojanen & Vuola, 2006).

Table 3.1: The basic dimensions of *R&D Performance* analysis

Measurement perspective for WHOM?	The purpose of the measurement WHY?	Measurement level WHERE?	R&D Type WHAT?	Process phase WHEN?
Customer	Strategic Control	Industry	Basic Research	Input
Internal	Justification of existence	Network	Exploratory research	In-process
Financial, shareholders	Benchmarking	Company	Applied research	Output
Other shareholders	Resource allocation	SBU/department	Product development	Outcome
Learning	Development of activities/problem areas	Process	Product improvement (incremental)	
Others	Motivation / reward	Project		
	Others	Team		
		Individual		

Source: Ojanen and Vuola, 2006, p. 285

A great number of indicators to measure *R&D performance* can be found in the literature, like the 391 indicators identified by Kerssens-van Drongelen and Bilderbeek (1999). Research has been moving forward in analyzing the measures that could give some assurance that the variables considered are those that have a positive effect on R&D performance (García-Valderrama & Mulero-Mendigorry, 2005; Henttonen, Ojanen, et al., 2016; Mulero Mendigorry, Garcia Valderrama, & Rodriguez Cornejo, 2016). The following section explores measures through the lens of process phases. It also considers some constraints related to R&D project type and finally makes some considerations on the traditional project management measurement approach.

3.1 The R&D Process Phases

Brown and Sverson (1988), using a systems approach, built the phases of an R&D lab, as shown in Figure 3.1. As described by these authors, *Inputs* are the resources used to generate the process in the system. The *Processing System* is where the R&D department converts inputs into outputs through projects that involve a set of activities. The *Output* is the phase immediately after the R&D Lab and is the immediate result of the R&D projects before being transferred to a business unit. The *Receiving System* comprises the various consumers of R&D outputs. *Outcomes* are the accomplishments that have value for the organization and receive more influence from operating process than from other areas.

Figure 3.1: The R&D lab laboratory as a system

Source: Brown and Svenson, 1988, p.106

Outcome measures are those that are more common in New Product Development literature to evaluate innovation, mainly at the firm level. Despite all the efforts to implement new methods and techniques to improve New Product Development, very little progress in success rates has been made when a broad sample is considered (Markham & Lee, 2013).

Table 3.2: Success Rates in new product development

	2012	2004	1995	1990
Successes	61%	59%	59%	58%
Successes-profit	56.2%	54.2%	54.6%	N/A
Sales from new products	31.1%	28%	32.4%	32.6%
Profits from new products	30.8%	28.3%	30.6%	33.2%
Number of ideas for one success	8.7	7.2	6.6	11

Source: Markham and Lee (2013, p. 413)

Bearing in mind the framework of this research, the measurement level to be investigated is the project level, which has received less attention in innovation research literature (Henttonen, Ojanen, et al., 2016) as most of the literature regarding collaborative R&D is at the

organization level (Chesbrough et al., 2014), where the research has advanced in a great number of issues, but there are some questions that can better be investigated at the project level.

The process view in R&D is suggested in several studies (García-Valderrama & Mulero-Mendigorri, 2005; Henttonen, Ojanen, et al., 2016; Mulero Mendigorri et al., 2016; Ojanen & Vuola, 2006), where R&D metrics are categorized by the phase of the R&D process (M. G. Brown & Svenson, 1988). Some typical outputs include patents, new products, new processes, publications or simple facts, principals or previously unknown knowledge. Outputs are measured in three dimensions: quality, quantity and cost. Outcomes are accomplishments that have value for the organization. For an R&D lab in a profit-making organization, the outcomes are accomplishments such as cost reduction, sales improvement, product improvements, new products, market share, and capital avoidance (M. G. Brown & Svenson, 1988). Knowing that outcomes are influenced by a myriad of factors (e.g. market factors, operations factors) that could hide the actual performance of the R&D project (Kerssens-van Drongelen & Bilderbeek, 1999), this study focuses on output measures.

Knowledge and knowhow are the main outputs from research systems and may be presented in various forms such as papers, articles and books, innovative prototypes, patents, consultancies, personnel training, teaching (Coccia, 2004). The output measures, according to Garcia-Valderrama and Mulero-Mendigorri (2005) (Figure 3.2), have two elements: achieving the objective stated in the R&D plan and budget, and results. The latter comprises tangible outputs related to knowledge acquisition by the firm through its R&D activities like the number of patents and utility models and papers published or presented at congresses and scientific meetings. Although patents and utility models are recognized as being the most widely used, it is also known that patents have a great variation regarding country and sector. However, it is very useful to compare homogeneous sectors. Participation in scientific meetings serves as an indicator of the firm's keenness to draw attention to the results obtained from research projects carried out within the organization or in collaboration with external partners (Mulero Mendigorri et al., 2016).

Figure 3.2: Dimensions and elements for R&D effectiveness measuring scale

Source: García-Valderrama and Mulero-Mendigorri (2005, p. 317)

To help solve the challenges of how to measure R&D performance, Mulero Mendigorri, Garcia Valderrama, and Rodriguez Cornejo (2016), based on the construct of García-

Valderrama & Mulero-Mendigorri (2005), empirically validated a scale for R&D effectiveness⁷, a broader concept that also includes output measures. Their research demonstrated that there are four factors which have most influence on the effectiveness of R&D: “the obtaining of results deriving from the company’s R&D activities; the union (i.e. close integration) of the R&D activities with company business strategy; proper planning of the R&D activities; and the existence of close relationships and cooperation between the company’s R&D, production and marketing functions” (Mulero Mendigorri et al., 2016, p. 346). The surveyed companies’ main indicators were also grouped into three factors, which include R&D performance measures related to: (i) execution of the projects (percentage of successful projects and percentage of projects finished on time) and their results (number of patents and number of publications); (ii) financial measures (financial ratios and balanced scorecard), and (iii) a third factor only included self-evaluations. The findings do not provide evidence that the use of different types of performance measures in R&D (project execution, financial and self-evaluation) is related to the effectiveness of R&D activities but they did identify the R&D performance measures (considering the whole R&D system) that have most influence on R&D effectiveness. The R&D outputs, in form of patents, contribution to conferences, publications and achievement of quality standards occupy fifth place in the ranking (Table 3.3). These authors suggest that this indicates that more importance is attached to the final results generated by R&D activities than the intermediate results. The tendency is to mainly measure effectiveness through outcomes although the intermediate outputs are also measured and are part of the R&D effectiveness scale (Mulero Mendigorri et al., 2016)(Mulero Mendigorri et al., 2016). Their research shows evidence that: (i) effectiveness in R&D is positively and significantly related to patent generation, company net turnover, and company profit after taxes; (ii) the percentage of profits accounted for by the sale of new product was a measure of R&D activities but not an indicator of their effectiveness. The main contribution of their findings is to jointly show the variables most frequently discussed in the literature for R&D measuring and their influence on R&D effectiveness. The variables of the effectiveness of R&D activities included in the scale and empirically validated are summarized in Table 3.3.

⁷ These authors identified some definition factors for R&D effectiveness in the literature: union of R&D and company strategy; effort devoted to R&D; proper planning of R&D activities; identification of market and R&D requirements; effective management of R&D personnel; effective transfer of technology to industry; the use of suitable financial criteria for R&D assessment; good cross-functional team work to exploit R&D results.

Table 3.3: Summary of the R&D effectiveness scale (R&D system)

R&D Production System Dimensions	Elements of each dimension	Measures
INPUTS	Abilities from R&D Human Resources #8	Abilities of R&D personnel Experience of R&D personnel
	Efforts from R&D #5	Expenses in research and development Spending intensity in R&D Personnel growth
	Adequacy of R&D planning #2	Communication of activities to be performed #1 Definition of results #3 Adequate R&D planning #4 Adequate design of R&D processes #2 Adequacy of objectives and financing in R&D #5
	External relations #7	Effects of legislation on R&D Influence of social actors
PROCESSES	Relations with other departments #3	Coordination between departments #2 Information about R&D to the rest of the company #3 Adaptation of production personnel #1
	Innovation from R&D #6	R&D process innovation #2 R&D product innovation #1
R&D OUTPUTS	R&D outputs #4	Scientific meeting participation #1 Patents #2 Achievement of quality parameters #3

Source: Based on Mulero Mendigorri et al. (2016)

is related to the relative importance of the variable on the scale.

Table 3.3: Summary of the R&D effectiveness scale (R&D system) - Continued

R&D Production System Dimensions	Elements of each dimension	Measures
R&D OUTCOMES	R&D outcomes #1	Market share #1
		Income #6
		Client satisfaction #2
		Client perception #3
		Client retention rate #5
		Positioning of the company #4
		Developed technology results #7

Source: Based on Mulero Mendigorri et al. (2016)

is related to the relative importance of the variable on the scale.

In summary, in the R&D system, *Performance* can be measure by each phase of the process. The most frequently used is *R&D Outcomes*, which comprises an evaluation of the whole system. However, to specifically evaluate the output directly linked to R&D activities, knowledge and knowhow are the main products and are mainly measured by explicit knowledge, in which patents and publications are the most widely adopted indicator. In addition to R&D output products, it is also important to measure the achievement of overall work quality that is related to parameters like time, cost and compliance with the quality standards. R&D outputs is also measured by innovation in product and process, however, as Henttonen et al. (2016) discussed, they seem to be very subjective until sales and financial figures are available.

3.2 Measuring performance by R&D type

Another dimension that received great attention is the *Type of R&D*. In this context, a seminal paper in R&D measures was published by Pappas and Remer (1985), who classified the research stage into types of evaluation techniques (R&D type, following the terminology of Ojanen and Vuola, (2006)), as presented in Figure 3.3 In this paper, the evaluation methods and

measures range from qualitative emphasis (basic research) via semi-quantitative (applied research) to quantitative emphasis (product development and improvement), with the following definitions (Pappas & Remer, 1985, p. 15):

“*Quantitative techniques* usually follow a specific algorithm or predefined ratio to generate numbers that can be compared with other projects and past experiences”.

“*Semi-quantitative techniques* are basically qualitative judgments that are converted to numbers.”

“*Qualitative techniques* are intuitive judgments.”

Figure 3.3 General uses of evaluation technique

Source: Pappas and Remer, 1985, p. 16

This discussion regarding different measures for different types of projects has been developing since Pappas and Remer (1985). There is a consensus that there is no one-size-fits all solutions in the set of appropriate measures for innovation and development projects. One of the most recent publications in this regard is by Henttonen et al. (2016), who identified that there are certain measures that seem to be important across all types of R&D projects like those related to the well-managed and rapid implementation of projects, customer satisfaction, and the level of innovativeness. And there are some that reflect the nature of specific project types. For example, research projects, in addition to subjective evaluations, also need some

quantifiable measures like number of patents, which, despite criticism, is still an important measure. They also identified that “qualitative metrics focus more on human performance as a measure of effectiveness, and their accuracy relies on the ‘goodness’ of the expert opinion” (Henttonen, Ojanen, et al., 2016, p. 924).

Table 3.4: Some references that categorized measures by type of R&D

Reference	Short description of the study
Brown and Gobeli (1992)	The authors categorised examples of R&D productivity indicators (as identified by study participants) into predominantly qualitative indicators and predominantly quantitative indicators.
Chiesa, Frattini, Lazzarotti, & Manzini (2009)	The study explored the interplay between measurement objectives, performance dimensions, and contextual factors in the design of an R&D performance measurement system. The contextual factors were the type of R&D, industry, and size. The empirical analyses with multiple studies of 15 Italian technology-intensive firms indicate that contextual factors (including the type of R&D) do not directly affect the choice of performance dimensions in the measurement systems, but their impact is mediated by the classes of objectives the firm decides to pursue.
Hauser and Zettelmeyer (1997)	The authors introduced a ‘tier metaphor’, which enabled the categorisation of a diverse continuum of projects, programmes and explorations, and a focus on key characteristics. For example, Tier 1 was defined as basic research, which attempts to understand basic science and technology. The study presented R&D metrics, both qualitative judgements and quantitative measures, reported by interviewees, as well as their relevance to the tiers.
Henttonen et al. (2016)	In a survey with 169 knowledgeable professionals from a company with a reputation in innovation, the study results indicate that which the most appropriate measures of project-level success are will depend on the form of innovation involved and the development project type. However, some measures can be seen as important across all types of R&D projects. The results of the study reveal the relatively low significance of financial measures for innovation projects in general.
Kim and Oh (2002)	In a survey of effective R&D performance measurement systems in South Korea, the categorisation was made based on the type of R&D. The types were basic R&D, applied R&D, and commercial R&D.
Kerssens-Van Drongelen and Bilderbeek (1999)	In another survey of R&D performance measurement, which was conducted in the Netherlands, the researchers categorised the types of R&D into basic research, applied research, and development. Surprisingly, the researchers did not find support for their proposition on differences in measurement procedures for applied research and for development.

Table 3.4: Some references that categorized measures by type of R&D - Continued

Reference	Short description of the study
Loch and Tapper (2002)	The authors categorised the measures of a ‘performance radar chart’ at Gem Stone into areas of knowledge repository, research process, new technologies, and technical support.
Pappas and Remer (1985)	The authors classified the performance measures techniques (quantitative, semi-quantitative and qualitative) by types of R&D projects. They suggest different technics for different types of projects due to the characteristics of the output in each project. For example, for basic research the quantitative technique is less applicable because the output is often too abstract.
Werner and Souder (1997)	The authors argued that the most successful approach to R&D effectiveness measurement appears to be integrated metrics that combine multiple objectives and subjective methods. The study presented examples of integrated metrics that contained an articulated but separable suite of quantitative and qualitative techniques that could be flexibly applied across all types of R&D.

Source: Partly adapted from Henttonen et al. (2016)

3.3 Traditional approach to Project Management measures

While diverse factors influence the selection of the appropriate measures for *R&D Performance* evaluation, measures related to project performance are well-established in *Project Management* literature and can be added to R&D (Henttonen et al., 2016) and innovation performance success measures (Markham & Lee, 2013).

“In general, a successful project was considered one that achieved its purpose, complied with the time-scales, fostered multifunctional cooperation, and was innovative in terms of satisfying customer needs. This seems to reflect the general trend for a modern R&D function to be ever more responsive to organisational needs, and ever less centrally protected and funded [...] This might also indicate that the company generally values project members who are able to deliver their projects on time and within budget. Previous literature also indicates that budgets, timescales, and customer needs have typically been prominent constraints in innovation and development projects over the past 20 years” (Henttonen et al., 2016, p.924).

With innovation projects facing shorter planning cycles, quicker reaction times and tighter financial constraints, project management performance measures are being considered to evaluate innovation project success rates. To demonstrate the adoption of these project management measures for *Innovation Performance* evaluation, the last Comparative Performance Study from Product Development Association [PDMA] adds *Time*, *Budget* and *Technical Quality* in their analysis as presented in Table 3.5 (Markham & Lee, 2013).

Table 3.5: Project Performance

	On Time (%)	On budget (%)	Met Technical Objectives (%)	Met Market Objectives (%)
Radical	29.2	31.7	53.1	46.3
More Innovative	43.6	49.1	66.3	58.7
Incremental	57.9	62.3	72.9	68.0

Source: Markham & Lee (2013, p. 412)

Although these *Project Management Performance* measurements are being considered for R&D measures and are gaining relevance to connect the R&D function to the organizational strategy, it is important to consider that the results of the measure results can be influenced by the planning competence of the team.

4. METHODOLOGY

4.1 Overview of the research design

In this study, we empirically examine the relationship of *R&D Collaboration* projects performance and project management success factors [PMSF], comparing the results between two knowledge source types: Science-based and Market-based (see Figure 4.1).

Figure 4.1: Research framework

Source: Elaborated by the Author

As previous research shows evidence that formal *Project Management* approaches have different impacts on performance in terms of the external knowledge source involved (Du, Leten, & Vanhaverbeke, 2014), we argue that some project management success factors might be contingent to the knowledge source involved in the project. Du et al (2014) identified the fact that *Project Management* formality is positively associated to financial performance for Market-based sources but negatively associated to financial performance for Science-based sources. Furthermore, a great number of studies have recognized challenges in R&D partnerships related to partner heterogeneity (Bjerregaard, 2010; Estrada, Faems, Martin, et al., 2016; vom Brocke & Lippe, 2015). However, some studies also provide evidence that the use of certain activities can help to attenuate the dissimilarities between partners (Bjerregaard, 2010; Bruneel et al., 2010; Estrada, Faems, Martin, et al., 2016). For these reasons, we argue that the use of certain types of project management success factors should increase the performance of the project, while others should decrease project performance, according to the knowledge source involved in the project.

Furthermore, the performance measure considered can also influence the result of the analysis, as not achieving the R&D outcome does not mean that the R&D project was not successful. As the *R&D Performance* can be measured in different phases of the R&D project life cycle, *R&D Output* measures are those that receive less influence from other areas like marketing and sales, which could hide the actual performance of the R&D project (Kerssens-van Drongelen & Bilderbeek, 1999). *R&D Outputs* are mainly measured by explicit knowledge, in which patents and publications are the most widely adopted indicator. In addition to *R&D Output* products, it is also important to measure the achievement of overall work quality, related to parameters like time, cost and compliance with the standards of quality, and the project performance. This is in line with current research that reflects the general trend for a modern R&D function to be increasingly more responsive to organizational needs and less and less centrally protected and funded (Markham & Lee, 2013).

Hence, a general hypothesis can be made:

Hypothesis 1: The effect of project management success factors on R&D project performance is different in terms of the external knowledge source involved in the R&D project.

This study used a quantitative exploratory approach, which does not seek to confirm pre-specified relationships or generalize the results. It expects to discuss the nature of the relationship between *Project Management Success Factors* and *Project Performance* in *R&D projects*, more specifically examine differences in the relationship nature by *Knowledge Sources*.

4.2 Operationalizing Project Management Success Factors in collaborative R&D projects

In *Project Management*, there are some practices classified as success factors, as discussed in Section 2.3. Barnes et al. (2006), conducting a case study, identified and classified factors that affect the success of heterogeneous R&D technological collaborations. In summary, these success factors were related to the benefits of having clearly defined objectives, responsibilities and roles, developing a project workplan to gain the commitment of partners, monitoring the progress of the project and develop effective communication.

Having clearly defined objectives, responsibilities and roles is one of these factors. The main related issue in these factors is being clear in definitions. Considering that at the front end of a project, the firm needs a process to connect it to the overall strategy, an important part of this connection is the establishment of clear and measurable goals (Clark & Wheelwright, 1993). This clarity simplifies the project and focuses on the actual work of development. Eight project management success factors related to clarity were analyzed (Table 4.1).

Table 4.1: Clearly defined objectives

Code	Project Management Success Factors	Measurement scale
CP1	Extension of expectation discussion	
CP2	Extension of sources of conflict discussion	
CP3	Quality of understanding of agreement	
CP4	Clarity in definition of objectives	Likert scale: 0 - 5
CP5	Clarity in definition of responsibilities	0 = strongly disagree
CP6	Clarity in definition of appropriation issues	5 = strongly agree
CP7	Clarity in definition of milestones	
CP8	Extension of being realistic in project aims	

Source: Elaborated by the Author

In a collaborative project, having mutually agreed plans enhances the confidence in the project (Barnes et al., 2006). Having a mutual agreement safeguards partners from misunderstandings during the evolution of the project due to the misalignment of partners' objectives and the low commitment. Furthermore, planning efforts aim to create a common perspective for the research project (Morandi, 2013) as diverse organizations might have various strategies, objectives, identities and missions, which increase the complexity of the project planning and execution in a collaborative project. Hence, seven project management activities related to mutual agreements were examined (Table 4.2).

Table 4.2: Mutually agreed project plan

Code	Project Management Success Factors	Measurement scale
MAPP1	Extension of joint discussion of the agreement	Likert scale: 0 - 5 0 = strongly disagree 5 = strongly agree
MAPP2	Extension of joint agreement of objectives	
MAPP3	Extension of joint agreement of responsibilities	
MAPP4	Extension of joint agreement of appropriation issues	
MAPP5	Extension of joint agreement of project milestones	
MAPP6	Extension of joint agreement of technical characteristics of human resources	
MAPP7	Extension of joint agreement of financial resources	

Source: Elaborated by the Author

During the project execution, a series of regular activities are conducted to monitor and provide support for a good project evolution. Regular progress monitoring involves evaluating the achievements of project milestones and taking corrective actions when necessary, including being flexible enough to react to changes (Barnes et al., 2002; Du, Leten, & Vanhaverbeke, 2014). The level of formality of this progress monitoring seems to have diverse impacts on knowledge sources (Du, Leten, & Vanhaverbeke, 2014). Table 4.3 presents a list of project progress monitoring success factors that were considered in this study.

Table 4.3 - Regular progress monitoring

Code	Project Management Success Factors	Measurement Scale
PM1	Extension of formal process monitoring with fixed time-frames.	Likert scale: 0 - 5 0 = strongly disagree 5 = strongly agree
PM2	Extension of conducting formal corrective actions to achieve the project plan.	
PM3	Extension of partner involvement in corrective actions.	
PM4	Level of flexibility in project execution to make changes due to new information.	

Source: Elaborated by the Authors

Effective communication is another success factor identified by Barnes et al (2002, 2006) and is related to having a robust communication strategy, combining formal mechanisms for strategy discussion and day-to-day management with informal communication to build team spirit and trust. In Table 2.5 some project management success factors described by diverse authors were classified by success factors. Those described for effective communication were used in the survey presented in Table 4.4.

Table 4.4: Effective communication

Code	Project Management Success Factors	Measurement Scale
EC1	Extension of training for collaborative work and inter-cultural awareness	
EC2	Extension of using continuous and open communication	
EC3	Extension of having clearly pre-defined communication strategies	
EC4	Extension of using of face-to-face meetings	Likert scale: 0 - 5 0 = strongly disagree 5 = strongly agree
EC5	Extension of encouraging informal communication	
EC6	Extension of using a common template to share overall project information	
EC7	Extension of centralization of communication	
EC8	Extension of having an employee external program focusing on knowledge integration	
EC9	Extension of using joint problem-solving tasks	

Source: Elaborated by the Author

4.3 Operationalizing Project performance measures in R&D

The dependent variable is an *R&D Project Performance* measure, which was operationalized through both quantitative *R&D Outputs*, subjective evaluation of the output, and project management measures.

For *R&D Output* measures, objective and subjective information was used. The first measure includes patent application or patent grants and scientific publications. As it would be difficult to compare an absolute number between very different projects, industries and countries, the survey asked for a comparison to be made between the output of the project selected and other projects from the same company. Therefore, the output was measured by comparison to other projects, considering the following options: better, the same or worse outputs. The qualitative evaluation was added to the *R&D Output* performance measurement. Despite the qualitative metric focus being more on human performance as a measure of effectiveness, and its accuracy relying on the ‘goodness’ of expert opinion (Henttonen et al., 2016), it helps to overcome the barrier of differences in terms of types of R&D and differences on how each company measures R&D output success. Therefore, a general evaluation of R&D success on a six-point Likert scale (the respondent indicated a value from 0 to 5 to evaluate the overall project success in terms of R&D output generated) was considered. However, this measure was added to the survey after starting collecting data, so a lower number of answers for the overall success evaluation is due to this late addition.

In terms of *Project Management Measures*, the traditional elements in this field (cost, time and quality) were considered. In the case of *Schedule Performance*, the evaluation includes late finishing, finishing on time, and early finishing. In the case of *Budget Performance*, the choices ranged from overrunning the budget, keeping exactly to the budget, being below the budget, and having no defined budget. *Quality* was defined as the *Technical Quality* of project execution, and a six-point Likert scale was used, going from “expectations not met” to “expectations surpassed”. These measures help to overcome the challenges related to measuring different types of project as they are related to the good management and rapid implementation of projects, which seems to be important across all types of R&D projects (Henttonen, Hurmelinna-Laukkanen, et al., 2016).

Table 4.5: Operationalization of *Performance Measures*

Code	Performance measure	Measurement Scale
Patent	Comparison of the number of patent applications with other companies’ projects.	2 = Better 1 = The same 0 = Worse
Publications	Comparison of the number of scientific publications with other companies’ projects.	2 = Better 1 = The same 0 = Worse

Table 4.5: Operationalization of *Performance Measures* - continued

Code	Performance measure	Measurement Scale
Budget	Actual project actual cost versus budget	Scale 0 – 6 0 = overran budget; 3 = the same as budget 6 = below budget;
Schedule	Actual project schedule versus planned project schedule	Scale 0 – 6 0 = finished late 3 = finished on time 6 = finished early
Quality	Technical quality of the project execution	Scale 0 – 5 0 = expectations not met 5 = expectations exceeded
Overall	Overall project success in terms of R&D output generated (subjective evaluation)	Scale 0 – 5 0 = expectations not met 5 = expectations surpassed

Source: Elaborated by the Authors

4.4 Other Variables

Moderating variables. Following previous literature (Du et al, 2014), this study distinguished two different group types of *Knowledge Sources* in R&D projects: (i) Science-based partners (universities and knowledge institutions – public and private) and (ii) Market-based partners (supplier firms, competitor firms, consultants). As in the data some projects used both types of sources, a third group, named ‘Both’, was included.

Control variables. The following control variables were considered: *Project complexity*; *Previous Link*; *Level of Uncertainty*; *Governance mode*; *Market Sector*. Table 4.6 describe each variable.

Table 4.6 - Control variables description and measurement scale

Code	Control variable	Measurement Scale
Project complexity	The higher the number of partners involved, the greater the complexity	From 0 to 10 or more partners (<= 2 lower complexity; >=3 higher complexity)
Previous Link	Whether projects were the first to be carried out with the partner or not. A mixed case with first time and not first-time partners was also possible.	First time Both first and not first-time partners Projects already carried out

Table 4.6 - Control variables description and measurement scale - Continued

Code	Control variable	Measurement Scale
Level of uncertainty	Type of R&D project. From Basic Research to product improvement, regarding the level of uncertainty. The higher the number in the measurement scale, the lower the uncertainty.	Basic Research Exploratory research Applied research Development Product improvement
Governance Mode	Type of relationship established with the partner	Outsourcing; Contract Research; Research Grant; Joint Research Project; Research Consortium; Joint Lab or Incubator Concept; Joint Venture

Source: Elaborated by the Author

4.5 The Instrument

The instrument was built based on the definitions explained above. However, a pre-test showed opportunities to add some success factors not previously considered. A pre-test was made with four R&D professionals from two multinational companies and two research leaders from a public research institute in Brazil. After answering the survey, they presented their doubts. With this information, the questionnaire was modified to provide a better understanding on what was being asked and what type of project should be considered. One of the pre-test participants suggested an additional activity related to the effectiveness of communication. More specifically, two pre-test participants informed that they also used an employee external program focusing on knowledge integration in collaborative R&D projects. As a result, we decided to add this activity in the list of Project Management Success Factors to the study.

4.6 Sample

The data comes from a survey with 53 collaborative R&D projects which were electronically collected using the Survey Monkey survey system. There is no data bank in Brazil grouping contacts from R&D professionals, and we did not have access to an international database. Therefore, a data bank was built based on the following:

1. Face-to-face meetings during the Open Innovation Week Seminar in Brazil in February 2017 (11 e-mails were sent after the face-to-face introduction).

2. Contact list from the World Open Innovation Conference in Santa Clara, CA, USA, in December 2015. Contacts from companies were identified in this list, so university professors and students were excluded (50 e-mails were sent).
3. Contacts from ISPIM (International Society for Professional Innovation Management) Innovation Conference in Vienna, Austria in June 2017. R&D professionals were identified from this conference list. As the contact information for most of them was from LinkedIn, a personal presentation was necessary to get the approval to send the survey link (9 contacts accepted this invitation).
4. Data bank from pharmaceutical companies registered in Brazil developed by Bataglia (2013). This data base included pharmaceutical related companies, like pharmacies. Therefore, a new list was generated considering just pharmaceutical companies (223 contacts received the e-mail).
5. Personal contacts of R&D professional in multinational companies in Brazil (12 e-mails were sent).

Finally, the data bank contained 335 contacts that received a request to answer the survey. An e-mail presenting the research and asking for R&D professionals to answer the survey was sent to these contacts, and, after a week without receiving an answer, a new e-mail asking for support was sent.

“I am a PhD student at the University of São Paulo/Brazil. My thesis focuses on Collaborative R&D projects and project performance, and I am trying to identify whether there are managerial success factors that would be contingent to the type of partner.

It is a quantitative study at the project level. At this moment, I am gathering data from people in R&D in companies all over the world. The results of this survey will be shared with the companies that are collaborating with it, and I hope it can improve managerial practices in Open Innovation.

As you the only contact I have in your Company, I would like to ask your help to invite R&D people (R&D project manager or research leader) to answer an electronic questionnaire. It takes 20 minutes.

The link is the following:

<https://pt.surveymonkey.com/r/colaborativeRnD>

As answers are provided at the project level, different members of the same company can answer various times for different projects. It is not the practices of the companies that are being analyzed but rather those used in specific projects with external partners.

The company name is optional as we are not interested in company results, but rather the company's collaborative R&D project.

Please let me know if you can collaborate or if you have any other suggestion to help me move forward with data collection.”

From 335 e-mails sent, the survey received 66 answers. After excluding all observations with relevant missing data, we ended up with 53 projects. Being exploratory, the number of observations may not have reached the ideal number for a conclusive statistical analysis. With this type of research, the results hope to contribute to a better understand of the problem and extract new insights for future studies. Of the 53 projects, just 37 answered the question regarding overall success evaluation. Therefore, specifically for this measure, the number of projects considered was lower.

Projects considered for the study must have been concluded within the past three years. To answer the survey, the R&D professional should have been involved in an R&D project with an external partner (see the Appendix C for the research instrument). There was no limitation regarding the location of the company or the respondent; however, due to access to contacts through conferences, personal contacts and a data bank built in Brazil it is important to be aware of a certain bias in terms of location and industry as most of the sample are from multinational companies that have a subsidiary in Brazil, and the majority are from pharmaceutical companies.

4.7 Data Analysis

To evaluate the influence of PMSFs on *Project Performance*, Pearson's correlation analysis, which measured the strength and direction of the linear relationship between a pair of variables, was used. In this study, each pair includes a PMSF and a performance measure. To do this analysis, the sample was divided by knowledge source types, and the correlation analysis was made after the sample division. Then, the results from each sample were compared and analyzed.

The correlation was calculated using the Microsoft Excel Software. The p value was described in the correlation tables by range: $p < 0.10$; $0.05 < p < 0.1$ and $p < 0.01$. A PMSF was considered critical when it is significantly correlated to the performance metric (correlation over 0.6 is considered strong correlation (Cohen, 1992)) at $p < 0.01$. As other variables may influence performance, control variables were evaluated using a Chi-square test to verify

whether the frequency distribution of variables differ between knowledge sources sample. If knowledge sources are homogeneous regarding control variables, we have evidence to believe that the significant correlations found must be due the relationship between the knowledge sources and the PMSFs.

A descriptive analysis was also made by comparing the PMSF used by the projects that had *The Best Performance Measures* and the others (*The Rest*). This comparison was carried out for each type of *Performance* measured and each type of source. The division between projects with *The Best* and *The Rest Performances* considered the middle of the scale, in each scale. More specifically, *Budget*, *Schedule*, *Technical Quality* and *Overall Performance* measures were evaluated as *The Best* when they received a score equal or above 3. This means that the project, at least, achieved the planned budget (*Budget* measure) and was finished on time (*Schedule* measure). For *Technical Quality Performance* and *Overall Performance*, the middle of the scale means that it received a positive evaluation (between expectation not met and exceeding expectation). The main concern was to consider just projects that was positively evaluated. For this, finishing on time and within the budget were considered positive evaluations. In the case of *Patents* and *Publications*, *The Best* projects were those that had, at least, the same number of patents or publications as other projects in the company.

5. RESEARCH RESULTS

5.1 Characteristics of the Sample

The characteristics of the sample are given in Table 5.1. Of the 53 projects that are part of the sample of this study, 43% have their headquarters in Brazil. However, the sample includes companies from Europe and USA, making up more than half of the sample, and 50% of companies from Europe are from Germany. The survey was answered by R&D professionals from diverse fields, most (30%) being from Pharmaceutical and Healthcare companies. Forty one percent were from companies that have less than 1,000 employees, and 37% from companies with more than 1,000 employees, including 11 huge and traditional multinationals. Nineteen projects were made with Market-based knowledge sources, 20 were with Science-based sources, and 14 with Both types. For the Science-based source, universities are the most frequent type of partner, and for Both types, universities are part of almost all projects. For the Market-based sources, suppliers are the most frequent. Forty seven percent of projects were made with first time partners, but they are more concentrated in the Science-based sample (48%). Seventy seven percent of the projects were made with 1 to 3 partners; 81% take up to 3 years; and 58% of the partners are from the same country, but not the same city. Furthermore, 53% of the companies have a dedicated unit to facilitate open innovation.

Table 5.1: Characteristics of the Sample

Variable	Both	Science	Market	Total
<i>Company headquarter</i>				
Brazil	5	7	11	23
EU	7	6	8	21
USA	2	5	1	8
Other	0	1	0	1
<i>Industry</i>				
Aerospace & Defense	0	0	1	1
Agribusiness	2	1	2	5
Autoindustry	1	2	4	7
Chemical	0	3	2	5
Diversified	0	1	0	1
Education	1	0	0	1
Energy & Oil & Gas	2	1	0	3
Health care	2	2	4	8
Pharmaceutical (+ Biotech)	1	4	3	8
Service	2	0	2	4
TI	1	0	0	1
Not informed	2	6	1	9

Table 5.1: Characteristics of the Sample - Continued

Variable	Both	Science	Market	Total
<i>Number of employees</i>				
< 1000	7	8	7	22
1.000 - 4.999		2	1	3
5.000 - 9.999	3	1	2	6
10.000 +	3	5	3	11
Not informed	1	3	7	11
<i>Previous Link</i>				
First time partners and old ones	6	2	2	10
Partners with previous link	4	5	9	18
Partners without previous link	4	12	9	25
<i>Knowledge sources</i>				
University	12	0	8	20
Private R&D Institute	4	0	7	11
Public R&D Institute	10	0	1	11
Supplier	10	10	0	20
Competitor	2	0	0	2
Consultant	0	2	0	2
Startup	2	4	0	6
<i>Number of partners</i>				
1 to 3	7	16	18	41
4 to 6	3	1	0	4
7 to 9	1	1	2	4
10 or more	3	1	0	4
<i>Project duration</i>				
1 year or less	2	4	6	12
2 to 3 years	7	13	11	31
4 years or more	4	2	3	9
Not informed	1	2	0	1
<i>Location of partner</i>				
Other country in another continent	1	6	4	11
Other country in the same continent	2	1	4	7
Same city	2	0	2	4
Same country, but not the same city	9	12	10	31

Source: Elaborated by the Author

To provide a broad view of PMSF use by knowledge source, the PMSFs mean was calculated. In general, all groups have their mean above the middle of the scale, as shown in Table 5.2. This suggests that PMSFs were used in all knowledge source samples. Taking PMSFs individually, just one activity related to *Effectiveness of Communication* had a score below 3. This activity is about having an *Employee Exchange Program* with the partner for

knowledge integration and is presented in Table 5.2, with more detailed information shown in the next section.

Table 5.2. Mean of project management success factors groups

	CP		MAPP		PM		EC	
	Mean	S.D	Mean	S.D	Mean	S.D	Mean	S.D
Market-based	3.96	0.14	3.98	0.16	3.92	0.07	3.43	0.37
Science-based	3.96	0.14	4.09	0.17	3.71	0.16	3.48	0.39
Both	3.87	0.15	3.94	0.16	3.82	0.07	3.55	0.27

Obs.: 6 point Likert scale

Source: Elaborated by the Author

5.2 Project Management Success factors and Performance

5.2.1 Projects with all types of sources

Taking all projects without differing them by knowledge source, we now present our analysis. Regarding performance, in general, *R&D Outputs* of the projects analyzed did not have a better performance in comparison to other R&D projects from the same company, as showed in Table 5.3. For the *Projects Performance Measures*, only *Technical Quality* was above the middle of the scale, which means that projects fulfilled expectations in this measure. Considering a more general and subjective evaluation, projects also fulfilled expectations, but did not exceed them.

Table 5.3 - Mean of performance measures in All types of sources

	Patent*	Publications*	Budget**	Schedule**	Technical Quality***	Overall***
Mean	1.0	1.1	2.2	1.8	3.6	3.5
S.D	0.7	0.7	1.4	1.4	1.0	1.2

* 3 point scale (worse; the same; better); ** 7 point scale; *** 6 point scale

The PMSFs, in general, were used. This is demonstrated by the mean score above 3 as shown in Table 5.4. Activities related to *Effectiveness of Communication* received the lower

evaluation, in general. However, this lower evaluation is mainly related to EC8, which informs us that, in this case, the employee exchange programs for knowledge integration was not used.

Table 5.4: Mean of PMSF evaluations for all sources

	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CPgroup
Mean	3.9	3.7	3.8	4.3	4.0	3.8	4.1	3.9	3.9
S.D.	1.0	1.2	1.1	0.9	0.9	1.1	0.9	1.0	0.15

	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	MAPPgroup
Mean	4.2	4.3	4.1	3.9	4.0	3.8	3.8	4.01
S.D.	1.0	0.9	0.9	1.0	0.9	1.0	1.1	0.16

	PM1	PM2	PM3	PM4	PMgroup
Mean	3.8	3.8	3.9	3.8	3.81
S.D.	1.1	1.2	1.0	1.1	0.04

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	ECgroup
Mean	3.0	3.8	3.6	3.9	3.7	3.5	3.7	2.4	3.8	3.48
S.D.	1.6	0.9	1.1	1.2	1.3	1.3	1.2	1.9	1.2	0.35

Source: Elaborated by the Author

To identify factors present in projects that had the best performance (projects rated above the middle of the scale), some figures with the PMSF ratings of these projects by performance measures are presented below. PMSFs are presented in the ranking in terms of *The Best*. On a six and seven-point Likert scale, *The Best* include those measures rated above 3 (for the seven-point scale, the middle is when the project was finished on time or had the same cost as the budget, achieving what was planned). For the three-point scale, exclusively used for *Patents and Publications*, *The Best* are those that received 1 (Similar to other projects) and 2 (Better than other projects).

5.2.1.1 PMSFs and Budget Performance

Almost 53% of the projects were evaluated with a score above 3 and are represented in *The Best* group. Figure 5.1 shows that only two PMSFs were below the middle on a scale from “strongly disagree” to “strongly agree”, which shows us some disagreement in terms of the use of *Employee Exchange Programs For Knowledge Integration* and *Having Training For Collaborative Work And Inter-Cultural Awareness*. In general, all PMSFs received a better

evaluation in *The Best* group, excluding the use of formal corrective actions to achieve the project plan during project reviews. Also, comparing the ranking for the two groups, some differences in the PMSF positions can be noticed. More specifically, PM3 and PM2 have a better position in the ranking (seventh and eighth, respectively) for *The Rest*, than for *The Best* (nineteenth and twenty-first, respectively). So, in general, activities related to *Progress Monitoring* was better evaluated by *The Rest* group, considering the position in the ranking.

Figure 5.1: Ranking of PMSFs for Budget Performance – all sources

The Best, n=29 (projects that received evaluation ≥ 3); The Rest, n= 24

Source: Elaborated by the Author.

5.2.1.2 PMSFs and *Schedule Performance*

Almost half of the projects were finished on time or even in less time than planned (*The Best*). However, the other half had really bad results, which helped to give a low mean for the *Schedule Performance* measure in general. It is interesting to note that all PMSFs were better evaluated by *The Best* group. The higher differences between *The Best* and *The Rest* scores are for CP2, EC1 and EC8, more specifically, *Discussion of Sources of Conflict*, *Training in Collaborative Work*, and *Employee Exchange Programs*, respectively. To complete the list of the greatest differences, EC5, EC7, MAPP6, EC6 and CP5 all had more than 0.7 difference in ratings. Figure 5.2 presents the ranking for PMSFs related to the *Schedule Performance* measure in the whole sample (all sources).

Figure 5.2 Ranking of PMSFs for *Schedule Performance* – all sources

The Best, n = 27 (projects that received evaluation ≥ 3); The Rest, n=26

Source: Elaborated by the Author

5.2.1.3 PMSFs and *Technical Quality Performance*

In four projects *Technical Quality Performance* received a rating lower than 3. Almost all PMSF evaluation means for these projects are below 3, which suggests that the PMSFs, were not intensively used. On the other hand, the PMSF evaluations for *The Best* projects were all better than *The Rest* projects, including those less used.

Figure 5.3. Ranking of PMSFs for *Technical Quality Performance* – all sources

The Best, n = 49 (projects that received evaluation ≥ 3); The Rest, n=4

Source: Elaborated by the Author

5.2.1.4 PMSFs and Overall Success Evaluation

The majority of projects (86%) received a positive overall evaluation in terms of *Output Generated*. These projects almost all used PMSFs, the only exception being the *Existence of an Employee Exchange Program for Knowledge Integration*. Additionally, all PMSFs were better evaluated by *The Best* than *The Rest* sample. The greater differences are precisely for the two PMSFs mostly used by *The Best*: *Jointly Agreeing about Objectives* and *Clearly Defining Objectives*.

Figure 5.4 - Ranking of PMSFs for Overall Success Performance – all sources

The Best, n = 32 (projects that received evaluation ≥ 3); The Rest, n=5

Source: Elaborated by the Author

5.2.1.5 PMSFs and R&D Outputs Performance Measures

Differing from the previous comparison between *Performance Measures* and PMSFs, *Patents and Publications* does not present, in general, a higher use of PMSFs in *The Best* projects. The only PMSFs related to *Effectiveness of Communication* were better evaluated by *The Best* group (both for *Patents and Publications*). More specifically, these PMSFs are: *Joint Use of Problem-solving Tasks*, and *Encouraging Informal Communication*. On the other hand, almost all the PMSFs were used (evaluation equal to or above 3) by both *The Best* and *The Rest* groups.

Figure 5.5 - Ranking of PMSFs for *Patent Performance* – all sources

The Best, n=42 (project that received evaluation of ‘The same’ or ‘better’); The Rest = 11
 Source: Elaborated by the Author

Figure 5.6 - Ranking of PMSFs for *Publications Performance* – all sources

The Best, n=42 (project that received evaluation of ‘The same’ or ‘better’); The Rest = 11
 Source: Elaborated by the Author

5.2.2 Projects with Market-Based Knowledge Source

The means of performance measures in the Market-based knowledge sample are presented in Table 5.5. In general, an excellent performance was not achieved in any measure. *Patents and Publications* is below 1, which means that projects with Market-based sources generally had a lower or the same number of patents or publications as other projects in the company. Projects failed in *Budget* and *Schedule Performance* measures, indicating that the budget was overrun and the project was completed late. The mean for *Technical Quality Performance* indicates that the quality of project execution met the expectations or exceeded

them. A more subjective measure, an evaluation of *Overall Success*, indicated that the respondent had a perception of a positive *R&D Output*.

Table 5.5 - Mean of Performance Measures in the Market-based Knowledge Sample

	Patent*	Publications*	Budget**	Schedule**	Technical Quality***	Overall***
Mean	0.95	0.89	2.16	1.74	3.42	3.00
S.D.	0.62	0.57	1.46	1.41	1.26	1.26

* 3 point scale (worse; the same; better); ** 7 point scale; *** 6 point scale

Source: Elaborated by the Author

Regarding the rating of the PMSF market sample, it is important to observe that, excluding EC8, the mean of all PMSFs was above three, as shown in Table 5.6. This indicated a generally high level of using PMSFs though PMSFs related to *Effectiveness of Communication* are the least used, even when EC8 is excluded.

Table 5.6 - Mean of PMSF Evaluations in the Market-based Sample

	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CPgroup
Mean	3.84	3.63	3.89	4.21	4.00	3.89	4.21	4.00	3.96
S.D.	0.96	1.12	0.99	0.98	0.88	0.94	0.85	1.25	0.14

	MAPP 1	MAPP 2	MAPP 3	MAPP 4	MAPP 5	MAPP 6	MAPP 7	MAPPgroup
Mean	4.16	4.21	4.11	4.00	4.00	3.63	3.79	3.98
S.D.	0.90	1.03	0.94	0.82	0.88	0.83	0.85	0.16

	PM1	PM2	PM3	PM4	PM group
Mean	3.89	3.84	3.89	4.05	3.92
S.D.	1.10	1.12	0.99	0.91	0.07

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	ECgroup
Mean	3.11	3.74	3.63	3.84	3.26	3.37	3.84	2.32	3.74	3.43
S.D.	1.33	1.05	1.07	1.34	1.63	1.26	1.17	1.89	1.28	0.37

Source: Elaborated by the Author

Continuing the identification of the differences of PMSFs used by *The Best* and *The Rest*, we now present the comparison by performance measure, as described in the previous section. In general, differences in the use of PMSFs between *The Best* and *The Rest* are higher in *Performance Schedule* and *Technical Quality* measures.

5.2.2.1 PMSFs and *Budget Performance*

The difference between the PMSFs used in *The Best* and *The Rest* in terms of *Budget Performance* is small. Actually, some PMSFs were evaluated higher in projects with the worst results in this measure as shown in Figure 5.7. The highest differences in evaluations, which means a higher use of the PMSF by *The Best* group, are for the *Discussing Expectations*, and *Sources of Conflict* PMSFs. Another case of *The Best* being better evaluated with a higher difference is for the last PMSF in the ranking, *Having an Employee External Program Focusing on Knowledge Integration*.

Figure 5.7 - Ranking of PMSFs for *Budget Performance* – Market-based Sources

The Best, n=9 (projects that received evaluation ≥ 3); The Rest, n= 10
Source: Elaborated by the Author

5.2.2.2 PMSFs and *Schedule Performance*

For the *Schedule Performance* measure the difference between the use of PMSFs for *The Best* and *The Rest* group is more evident than for *Budget Performance*. Excluding EC9 (*Using Joint Problem-solving Tasks*) and EC8 (*Having Employee External Programs for Knowledge Integration*), which have close means, a greater difference between practices is evident in almost all the cases. It is interesting to see that even for *The Rest* group, practices were used

(mean above 3), but with a lower intensity. PMSFs related to communication were the least used for both groups. *Clear Planning* and *Mutually Agreeing on PMSFs* received the highest scores. PMSFs related to progress monitoring also have a mean of 4, indicating intense use.

Figure 5.8 – Ranking of PMSFs for *Schedule Performance* – Market-based Sources

The Best, n = 8 (projects that received evaluation ≥ 3); The Rest, n=11

Source: Elaborated by the Author

5.2.2.3 PMSFs and *Technical Quality Performance*

Projects with *The Best Technical Quality Performance* have the highest ratings for all PMSFs, even those with lower scores. The PMSFs mostly used by *The Best* are related to the groups of *Clear Planning* and *Mutual Agreements*. The first five PMSFs in the ranking are related to defining project objectives, responsibilities and discussing expectations, both clearly defining and jointly agreeing on them. The PMSFs related to *Effectiveness of Communication* were evaluated lowest; however, *Face-to-face Meetings*, *Using Joint Problem-solving Tasks* and *Centralized Communication* were used. PMSFs related to *Progress Monitoring* were all above the middle of the scale, suggesting that these factors were present.

Figure 5.9 Ranking of PMSFs for *Technical Quality Performance* – Market-based Sources

The Best, n = 16 (projects that received evaluation ≥ 3); The Rest, n=3

Source: Elaborated by the Author

5.2.2.4 PMSF and *Overall Success Evaluation*

Regarding overall success evaluation, in general, both groups of projects (The Best and The Rest) used almost all PMSFs (mean above 3). However, those with best results received better ratings in some of them. The major differences between the PMSF evaluations are for CP7 (*Clarity in Milestone Definitions*), CP4 (*Clarity in Definitions of Objectives*), PM1 (*Formal Process Monitoring*), and PM4 (*Flexibility in Project Execution*). It is also interesting to observe that projects that received the best overall evaluation also had better *Patent, Publications and Schedule Performance* in terms of means.

Figure 5.10. Ranking of PMSFs for Overall Success Evaluation – Market-based sources

The Best, n = 8 (projects that received evaluation ≥ 3); The Rest, n=3

5.2.2.5 PMSFs and R&D Outputs Performance measures

With a higher number of PMSFs better evaluated in *The Rest* than in *The Best*, the *Patent Performance* measure has a different result in comparison to the other measures already presented. The group with the best performance results has the same or a higher number of patents in comparison to other company projects. This group has a lower level of variance between the most and least used PMSFs, with, in general, only the *Employee Exchange Program* not being used by *The Best* group.

Figure 5.11. Ranking of PMSFs for Patent Performance – Market-based sources

The Best, n=15 (project that received evaluation of 'The same' or 'better'); The Rest = 4

Source: Elaborated by the Authors

A very similar behavior to the *Patent* measure can be seen in *Publication Performance*. Figure 5.12 shows the comparison between the group evaluated as having a higher or similar number of publications (*The Best*) and the group with the lower number (*The Rest*) related to other company projects.

Figure 5.12. Ranking of PMSFs for *Publication Performance* – Market-based sources

The Best, n=15 (project that received evaluation of 'The same' or 'better'); The Rest = 4

Source: Elaborated by the Author

5.2.3 Projects with Science Based Knowledge Source

In general, projects with Science-based sources have certain performance measures whose means are above the middle of the scale, as shown in Table 5.7.

For *Patents and Publications*, the mean of 1.10 shows us that R&D projects evaluated in the survey have a similar result (or a little better) than *Publications and Patents* in comparison to other company projects.

In case of *Budget and Schedule* performance measures, projects failed, indicating that the budget was overrun, and the project was completed late.

The mean for *Technical Quality Performance* indicates that the quality of project execution fulfilled expectations or exceeded them. For an evaluation of overall success, the respondent had a perception of a positive R&D output.

Table 5.7: Mean of Performance measures in Science-based knowledge Sample

	Patent*	Publications*	Budget**	Schedule**	Technical Quality***	Overall***
Mean	1.10	1.10	2.70	2.00	3.75	3.33
S.D	0.79	0.79	1.42	1.45	0.97	1.40

Source: Elaborated by the Author

While some *Performance* measures means are below the middle of the scale, all PMSF measures are above it (Table 5.8). These high scores for PMSFs informs us that, in terms of means, all factors were present in the projects with Science-based sources. The factor least used is related to *Effectiveness of Communication*, more specifically the *Extent of Training for Collaborative Work and Inter-cultural Awareness*, and the *Use of an Employee Exchange Program*.

Table 5.8 - Mean of Evaluation of PMSFs in the Science-based sample

	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CPgroup
Mean	3.90	3.80	3.80	4.35	4.15	3.95	3.95	3.80	3.96
S.D.	1.21	1.36	1.28	0.99	1.04	1.10	1.10	0.89	0.14

	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	MAPPgroup
Mean	4.25	4.35	4.25	4.05	4.00	4.00	3.70	4.09
S.D.	1.25	0.99	1.02	1.00	1.08	1.21	1.34	0.17

	PM1	PM2	PM3	PM4	PMgroup
Mean	3.50	3.75	4.00	3.60	3.71
S.D.	1.28	1.45	1.03	1.35	0.16

	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	ECgroup
Mean	2.80	3.95	3.45	3.80	4.05	3.50	3.65	2.45	3.65	3.48
S.D.	1.79	1.00	1.32	1.40	1.05	1.36	1.14	1.96	1.39	0.39

Source: Elaborated by the Author

Similarly to Market-based sources, we identified *The Best* performance results (above the middle of the scale) and split them from *The Rest*, then comparing the evaluations of the PMSFs. This comparison is presented below by type of performance measure.

5.2.3.1 PMSFs and *Budget Performance*

In general, all the PMSFs were better evaluated in projects with *The Best Budget Performance*, as Figure 5.13 shows. The PMSFs with the highest differences between *The Best* and *The Rest* groups were *Using an Employee Exchange Program*, *Mutually Agreeing on Financial Resources*, *Clearly Defining Project Milestones*, *Agreeing on the Technical Characteristics of Human Resources*, and *Using Corrective Actions during Project Reviews*.

Figure 5.13 - Ranking of PMSFs for *Budget Performance* – Science-based Sources

The Best, n=15 (projects that received evaluation ≥ 3); The Rest, n= 5

Source: Elaborated by the Author

5.2.3.2 PMSFs and *Schedule Performance* measure

When comparing the use of PMSFs between *The Best* and *The Rest*, according to the *Schedule Performance* measure results in Figure 5.14, it can be seen that PMSFs in both groups were used (above the middle) in almost all cases, excluding *Employee Exchange Program* and *Training in Collaborative Work and Inter-cultural Awareness*, which were below the middle

for *The Rest* group. These two PMSFs, though not receiving the highest scores in *The Best* group, should receive some attention as they have the highest differences between the groups. Some PMSFs in *The Rest* group received a higher rating than *The Best* group: *Mutually Agreeing about Financial Resources*, *Use of Face-to-face Meetings*, and *Clearly Defining Appropriation Issues*.

Figure 5.14 - Ranking of PMSFs for Schedule Performance – Science-based Sources

The Best, n=12 (projects that received evaluation ≥ 3); The Rest, n= 8

Source: Elaborated by the Author

5.2.3.3 PMSFs and Technical Quality Performance

The comparison between *The Best* and *The Rest* projects according to *Technical Quality Performance* was not made using the same type of graph used for other measures, as only one project informed that it had *Technical Quality* below the middle of the scale. This project with a lower result did not use any of the project management practices. So, in Figure 5.15 we present a ranking with PMSFs used in projects that had a score above or equal to 3. The least used PMSFs are those of *Effectiveness of Communication*, like *Using a Common Template to Share Project Information*, *Defining Communication Strategies between Partners*, *Training in Collaborative Work*, and *Inter-cultural Awareness*, and the *Use of Employee Exchange Programs to Enhance Knowledge Integration*; however, informal communication was encouraged. On the other hand, *Discussing Expectations across all Partners*, and *Mutually Agreeing on Objectives, Agreement and Responsibilities* were the best evaluated PMSFs.

Figure 5.15: Ranking of PMSFs for Technical Quality Performance – Science-based sources

The Best, n=19 (projects that received evaluation ≥ 3);

Source: Elaborated by the Author

5.2.3.4 PMSFs and Overall Success Evaluation

Of the fourteen projects that received answers to *Overall Evaluation of Success*, 12 received an evaluation equal to or above 3. Figure 5.15 presents the ranking of the PMSF evaluations of these projects. Excluding EC8 and EC1, all PMSFs were above the middle of the scale. This demonstrates the use of almost all PMSFs in projects in *The Best* group. PMSFs related to *Effectiveness of Communication* are those less used. In addition, although PM1 is informed as being used, it is the one of those evaluated lowest. On the other hand, factors related to *Mutually Agreed Activities* and *Clear Planning* are those which are best evaluated.

Figure 5.16: Ranking of PMSFs for Overall Performance Evaluation (The Best) – Science-based Sources

The Best, n=12 (projects that received evaluation ≥ 3);

Source: Elaborated by the Author

5.2.3.5 PMSFs and R&D Output Performance measures

Contrasting with previous results in projects with Science-based sources, the comparison between *The Best* and *The Rest* groups for R&D outputs have different behaviors. This was also perceived for the market-based sample. Figures 5.16 and 5.17 show that there are a higher number of PMSFs used in *The Rest* than in *The Best* group. While there is no great difference between PMSFs mostly used by *The Best* and *The Rest*, the differences should be discussed. For *Patent* measures, PMSFs related to *Effectiveness of Communication* were those with the highest differences (considering those which *The Best* most used). Note that of the nine PMSFs that *The Best* most used, seven are related to *EC*. Additionally, in the MAPP group the only PMSF *The Best* used more is that related to *Jointly Agreeing on the Technical Characteristics of Human Resources for the Project*.

Figure 5.17 - Ranking of PMSFs for Patent Performance – Science-based Sources

The Best, n=14 (project that received evaluation of 'The same' or 'better'); The Rest = 5

Source: Elaborated by the Author

For the *Publications* measure, it can be seen that that all PMSFs related to *Progress Monitoring* were more used by *The Rest* group. More specifically, this means the higher use of the following factors: *Formal Review Cycles with Fixed Time Frames*, *Corrective Actions to Achieve the Project Plan* (including discussing it with partners), and allowing some flexibility in the project plan due to new unforeseen opportunities. On the other hand, *The Best* group used

more, with greater differences, the *Joint Agreement of Financial Resources* PMSF. It is also important to notice that, despite receiving an evaluation below the middle of the scale, which means not agreeing with the presence of the success factor, the *Employee Exchange Program* was better evaluated by *The Best* group.

Figure 5.18 - Ranking of PMSFs for *Publication Performance* – Science-based Sources

The Best, n=14 (project that received evaluation of 'The same' or 'better'); The Rest = 5

Source: Elaborated by the Author

5.2.4 Projects with *Both Types of Knowledge Source*

Following the same pattern as the other sources, performance for *Budget* and *Schedule* measures came below the middle of the scale. This shows us that, in general, projects with Both types of sources overrun the budget and are finished late. For *Technical Quality Performance*, projects received a positive evaluation (fulfilled expectations but did not exceed them). In the case of *Patent and Publication* measures, evaluated projects had a similar result to other company projects. Finally, the *Overall evaluation of R&D Project Output* was positive.

Table 5.9 - Mean of Performance measures in Both Knowledge Source Sample

	Patent*	Publications*	Budget**	Schedule**	Technical Quality***	Overall***
Mean	1.1	1.2	1.7	1.6	3.6	4.1
S.D	0.7	0.7	1.2	1.5	0.5	0.7

* 3 point scale (worse; the same; better); ** 7 point scale; *** 6 point scale

Source: Elaborated by the Author

Analyzing the mean score for PMSFs in the Both sample in Table 5.10, excluding EC8, all PMSFs were positively evaluated. Also in the EC group, *Training for Collaborative Work and Inter-cultural Awareness* had the lowest score.

Table 5.10 - Mean of PMSFs Evaluations in the Both Knowledge Sources sample

	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	CPgroup	
Mean	3.9	3.5	3.8	4.2	3.8	3.5	4.1	3.9	3.9	
S.D.	1.0	1.1	0.8	0.8	0.8	1.2	0.7	0.8	0.15	
	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	MAPPgroup		
Mean	4.0	4.3	3.8	3.5	4.1	3.8	4.0	3.9		
S.D.	0.6	0.7	0.7	1.3	0.8	0.7	0.9	0.16		
	PM1	PM2	PM3	PM4						PMgroup
Mean	4.0	3.8	3.6	3.8						3.8
S.D.	0.8	0.8	1.0	0.8						0.07
	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9	ECgroup
Mean	3.0	3.8	3.6	4.1	3.7	3.5	3.4	2.6	4.0	3.5
S.D.	1.6	0.9	1.1	0.7	1.1	1.5	1.5	0.8	0.9	0.27

Source: Elaborated by the Author

5.2.4.1 PMSFs and *Budget Performance*

The sample that comprises *The Best* projects in *Budget Performance* made with both types of sources generally has all PMSFs equal to or above three. The only exception is EC8. These evaluations suggest that respondents agree with the statements of the presence of PMSFs. The highest evaluated factor in this group was related to *Progress Monitoring*. More specifically, 60% of respondents in *The Best* group informed that they strongly agree that the project should

use a plan/ execution/ review cycle with fixed time frames. The two PMSFs with highest differences between *The Best* and *The Rest* group are those that received the highest scores: PM1 and EC7. Adding EC6 and EC5, we have the PMSFs with the greatest differences in the evaluation of the two groups. These factors related to *Effectiveness of Communication* show us that there is greater difference in the evaluation related to *Using Centralized Communication* (one person in each team responsible for making the communication), and *Using a Common Template to Share Overall Information of the Project*. In addition, *Informal Communication* was also encouraged.

Figure 5.19 Ranking of PMSFs for Budget Performance – Both Knowledge sources Sample

The Best, n=5 (projects that received evaluation ≥ 3); The Rest, n= 9

5.2.4.2 PMSFs and Schedule Performance

Projects with *The Best* results in the *Schedule performance* measure used all the PMSFs investigated in the survey. The sample with *The Rest* projects show some PMSFs with evaluations below the middle of the scale: CP2, EC1 and EC8. Also, almost all PMSFs were better evaluated by *The Best* group. This therefore suggests that projects that have a better *Schedule Performance* used all PMSFs, with more emphasis on some of them as there is some variation in their use, while projects with poorer results did not use all PMSFs and used the PMSFs most used by *The Best* group, but with less frequency.

Figure 5.20 Ranking of PMSFs for *Schedule Performance* – Both Knowledge Sources Sample

The Best, n=7 (projects that received evaluation ≥ 3); The Rest, n= 7

Source: Elaborated by the Author

5.2.4.3 PMSFs and *Technical Quality* performance

All projects in the both samples received an evaluation above 3 for *Technical Quality* performance. Therefore, the ranking presented in Figure 5.20 has just *The Best* projects. Excluding EC8, all PMSFs received an evaluation above 3, showing that PMSFs were generally used. However, the level of agreement as to their use varies, and this can be seen in the ranking. Those with evaluations above the mean score of 4 are from diverse types of activities. More specifically, they used some *Joint Decisions*, were *Clear in Defining Objectives and Milestones*, and they also used *Face-to-face Meetings and Joint Problem-solving* tasks.

Figure 5.21 - Ranking of PMSFs for *Technical Quality Performance* – Both Knowledge Sources Sample

The Best, n=14 (projects that received evaluation ≥ 3); The Rest, n= 0

Source: Elaborated by the Author

5.2.4.4 PMSFs and Overall Success Performance

All projects in the ‘Both’ sample received an overall success evaluation above 3. Hence, Figure 5.21 provides information only for one group *The Best*. These projects used all PMSFs (score above 3). The PMSFs with a better evaluation (equal to or above 4) are mainly related to activities of *Jointly Agreeing on some Decisions* and *Clear Planning*, but there is also an activity related to *Effectiveness of Communication*. More specifically, *Jointly Agreeing on Objectives, Milestones, Financial Resources and the Agreement*, *Clearly Defining Objectives, Milestones, Expectations, Responsibilities* and *Being Realistic in Project Aims*, and also the *Use of Face-to-face Meetings* are the PMSFs with top scores in the ranking.

Figure 5.22 - Ranking of PMSFs for Overall Success Performance – Both Knowledge Sources Sample

The Best, n=11 (projects that received evaluation ≥ 3); The Rest, n= 0

Source: Elaborated by the Author

5.2.4.5 PMSFs and R&D Output Performance

In the case of *Patent and Publication Performance* there are a large number of PMSFs that were better evaluated in *The Rest* group. In the case of *Publication Performance*, the number of PMSFs with higher evaluations are in *The Rest* group. Therefore, in this case and with this descriptive analysis, we cannot say that the greater the use of PMSFs, the higher the performance measure. However, we can notice that in case of *Patents*, the PMSFs with the

highest difference for *The Best* group are related to *Effective Communication*: EC5, EC6, EC7, EC3 and EC1. In case of *Publication* group, they are: EC5, EC9, EC2.

Figure 5.23 - Ranking of PMSFs for *Patent Performance* – Both Knowledge Sources Sample

The Best, n=11 (project that received evaluation of ‘The same’ or ‘better’); The Rest = 3

Source: Elaborated by the Author

Figure 5.24 - Ranking of PMSFs for *Publication Performance* – Both Knowledge Sources Sample

The Best, n=12 (project that received evaluation of ‘The same’ or ‘better’); The Rest = 2

Source: Elaborated by the Author

5.2.5 Comparing the PMFS by types of sources

To discuss the differences between the use of PMSFs by knowledge sources, we developed a comparative table with the mean of *The Best* projects, by *Performance measure* and by knowledge source. The table is presented in Appendix F.

In general, there are not great differences between the use of PMSFs by knowledge sources in all measures in the samples of *The Best* projects. The ones that were less used are related to *Effective Communication*. The greatest difference in this group was found in the level of *Encouraging Informal Communication*. This PMSF was less used in projects done with Market-based sources and more used (almost all cases) in projects done with Science-based sources. Also, *Having an Employee Exchange Program Focusing on Knowledge Integration* was not used in almost all cases, excepted by projects made with Science-based sources (budget, schedule measures) and Both sources (*Schedule* and *Overall evaluation*).

Another PMSF use that shows great differences between the knowledge sources is that related to the level of use of *Formal Process Monitoring with Fixed Time-Frames*. In this case, projects made with Science-based sources were those which used it less. However, when it was related to fulfilling the Budget of the project, this PMSF was evaluated with the same mean both for projects made with Science-based as for projects done with market-based sources. This might suggest that when a *Formal Process Monitoring* is used, the Budget of the project have better results, including for projects carried out with Science-based sources.

A great number of PMSFs had their mean over 4 (Appendix F put this higher level of use in evidence), which shows that the PMSFs were heavily used, especially those ones related to *Clear Planning* and *Mutually Agreeing the Project Plan*. In projects with *The Best* Schedule performance, a great number of PMSFs received this high score. In this case, projects made with Market-based sources had the greater number of PMSFs being strongly used. In addition, it is interesting to notice that projects carried out with Both sources, especially the ones with *The Best* performance in *Budget* measure, strongly used almost all PMSF.

To compare the differences between the PMSF used by *The Best* and *The Rest* projects by knowledge sources, in Appendix G we present a Table with this evaluation. The greater number of differences between *The Best* and *The Rest* projects were found when the whole sample were considered together (all sources). In this case, projects with *The Best* performance in *Technical Quality* were the ones that had the highest difference in using PMSFs, especially

for the *Clear Planning* group. This can suggest that these PMSFs were the ones that had greater influence in enhancing the Technical Quality of the R&D project in collaboration (without evaluating the differences by knowledge sources). However, a closer look at the differences by source, show diverse results as most of the PMSFs with the greater difference between *The Best* and *The Rest* performance are different between the knowledge sources and also by performance measure.

In addition, continuing with the evaluation of the differences, it is interesting to notice that there are some differences that give a negative result. This means that projects with worse results (*The Rest*) used certain PMSFs more, than projects with *The Best* results, suggesting that the higher use of these PMSFs did not enhanced the performance. Most of these cases with negative results are found in Patent and Publication measures. Looking further in these R&D Output measures we can also notice that, the greatest number of PMSFs more used by *The Best* projects are related to *Effective Communication*.

This descriptive analysis of the sample provided some information about the differences in the use of the PMSFs by projects made with different types of knowledge sources. Evaluating the differences provided some evidence that PMSFs strongly used in projects with *The Best* performance varies by type of knowledge source involved in the project, but also varies by type of performance measures. The negative results showed us that the use of some PMSFs did not enhanced the performance of the project, which is more evident in terms of Patent and Publication measures.

Moving forward in the evaluation of the influence of PMSFs on project performance by knowledge source, a Pearson's correlation analysis, which measured the strength and direction of the linear relationship between a pair of variables (PMSFs x performance), is presented in the next section.

5.3 Correlations results

Pearson correlation tables were generated relating a pair of variables: *Performance Measure* and *Project Management* activities. This correlation was made for each sample, which includes the type of partner involved in the project (Appendix H, I, J, K). Basically, we have three samples: Market-based, Science-based and Both-based sources. The results and the

comparisons are described by type of performance measure. Correlations above 0.6 were considered critical and significant for $p < 0.01$, and they are summarized in Table 5.11 (A summary Table with all PMSFs is presented in the Appendix D and E).

Table 5.11: Summary of critical correlations

PMSF by Performance Measure	Market (n=19)	Science (n=20)	Both (n=14)
<i>Technical Quality</i>			
Extent of expectation discussion (CP1)	0.10	0.78*	0.25
Clarity in definition of objectives (CP4)	0.28	0.64*	0.23
Clarity in definition of responsibilities (CP5)	0.15	0.61*	0.06
Extent of joint agreement of technical characteristics of human resources (MAPP6)	0.26	0.71*	0.21
Extent of encouraging informal communication (EC5)	0.02	0.63*	0.67*
Extent of using joint problem-solving tasks (EC9)	0.04	0.48	0.70*
<i>Schedule</i>			
Extent of sources of conflict discussion (CP2)	0.71*	0.40	0.59
Clarity in definition of responsibilities (CP5)	0.76*	0.38	0.09
Clarity in definition of appropriation issues (CP6)	0.60*	0	-0.02
Clarity in definition of milestones (CP7)	0.60*	0.23	0.11
Extent of joint agreement of appropriation issues (MAPP4)	0.67*	0.22	0.06
Extent of joint agreement of projects milestones (MAPP5)	0.67*	0.17	0.14
Extent of joint agreement of financial resources (MAPP7)	0.64*	-0.11	0.18
Extent of formal review cycle with fixed time-frames (PM1)	0.62*	0.11	0.21
Extent of having clearly pre-defined communication strategies (EC3)	0.70*	-0.11	0.41
<i>Budget</i>			
Extent of formal review cycle with fixed time-frames (PM1)	0.22	0.38	0.68*
<i>Patent</i>			
Extent of expectation discussion (CP1)	-0.03	-0.10	0.67*

* Correlation is Significant at the level $p < 0.01$.

These correlation results show support for Hypothesis 1, which predicted that the effect of PMSFs on R&D project performance would be different in terms of the *external knowledge source* involved in the project. This is justified by some PMSFs being positively and significantly associated to *performance* but with diverse results according to the knowledge source involved in the project. Note that the only PMSF that is present in projects with Science-based partners (*Technical Quality*) and Market-based partners (*Schedule Performance*) is CP5

($r=0.61$; $p<0.01$ and $r=0.76$; $p<0.01$). This suggests that there is a need to be clear in defining responsibilities in *Collaborative R&D Projects* to improve these *Performance* measures. More specifically, *Being Clear In Defining Responsibilities* might positively affect the *Technical Quality* of projects made with Science-based sources and the *Schedule Performance* in projects made with Market-based sources.

Not only are PMSFs different in terms of knowledge sources, they also have diverse effects on different *Performance* measures. In projects with Science-based sources, the PMSF correlation is critical for the *Technical Quality* measure. Differently, in projects with market-based sources, correlation is critical for the *Schedule Performance*. In the case of both sources being involved in the project, the PMSF correlation is critical for the *Budget Performance* measure. This therefore suggests that the use of PMSFs differently affects not only success according to *Knowledge Source* but also *Measured Performance*. More specifically, the use of a certain PMSF (or PMSFs) in a project made with a specific knowledge source might improve one performance measure but not all of them. Hence, there is no positive and significant association for all PMSFs and all *Performance* measures, which constrains the statement that the use of *Project Management Success Factors* enhances *R&D Performance* in *Collaborative Projects*. This is observed both in projects with a Science-based and those with a Market-based knowledge source. The following section describes each of the types of performance measure.

5.3.1 *Technical Quality Performance Measure*

Technical Quality Performance was the PMSF with the best performance evaluation in both the Market-based and the Science-based sample, as shown in previous section. The mean of this performance measure received a positive evaluation in all cases. In the case of projects in the Both-based sample, all projects were evaluated as having a positive performance in this measure. We also identified, in the comparison between projects with better results and the others, the fact that PMSFs were not equally used by all projects. Thus a comparison between the correlation of this measure and PMSFs for each knowledge source was made.

While no correlation was found when all sources were analyzed together, some variations appear when they are investigated individually, as shown in Table 5.11. A group of PMSFs is listed in this table informing us of those that received a critical correlation. Correlations between technical quality and PMSFs have critical and significant results only for Science-based and Both-based knowledge sources. In the Science-based knowledge source most of the critical

correlations are related to *Clear Planning*, one is related to *Making Joint Decisions*, and one to *Effectiveness of Communication*. More specifically, *Clearly Defining Objectives and Responsibilities*, *Discussing Expectations with all Partners* (the highest correlation in this sample $r=0.87$; $p<0.01$), *Jointly Agreeing on the Technical Characteristics of Human Resources*, and *Encouraging Informal Communication* are the success factors that have a positive and significant effect on *Technical Quality Performance* when the R&D project is made in collaboration with a Science-based source. No critical correlation exists for PMSFs related to progress monitoring in this measure. It therefore seems that when working in projects with Science-based sources the phase before project execution (*Discussion of Expectations*, *Defining Objectives and Responsibilities*, and *Jointly Agreeing on Human Resource Characteristics*) is critical in order to improve the technical quality of the project. However, during the project, *Informal Communication* (EC5) should be encouraged as all samples that involve at least one Science-based source have a critical positive correlation to this PMSF for *Technical Quality Performance*.

Table 5.11 also shows that PMSFs that have a critical and significant correlation to technical quality performance in Both-based sources are related to *Effectiveness of Communication*. Therefore, *Encouraging Informal Communication* and *Using Joint Problem-solving Tasks* has a positive influence on *Technical Quality Performance* in projects carried out in Both-based sources.

5.3.2 Schedule Performance Measure

Although half of the whole sample had a positive evaluation of *Schedule Performance* (equal to or over 3), which means that projects finished on time or even earlier, in a general mean, the performance was evaluated as being negative. In the comparison between *The Best* and *The Rest* projects in *Schedule Performance*, made in the previous section, we identified that projects used PMSFs differently. This difference is demonstrated by comparing the position in ranking and the evaluation rating for each PMSF between knowledge sources. However, this comparison does not inform us of an association between the use of a PMSF and its effect on *Performance*. To move forward in our analyses, the results of the correlation between PMSFs and *Schedule Performance* by knowledge source are presented in Table 5.11 and support our Hypothesis (H1) as PMSFs with critical and significant correlation between sources are different by knowledge source used in the project. More specifically, correlation with critical

and significant results in this measure appear only for the Market-based knowledge source sample.

Projects with Market-based sources present critical and significant correlation for PMSFs related to all issues. Like PMSFs correlated to Science-based sources in the technical quality measure, *Clearly Planning the Project* also has the highest number of critical and significant correlations. However, they are different in comparison to Science-based sources. For Market-based sources, in the *Schedule Performance* measure, the PMSFs are related to *Discussing the Sources of Conflict* (CP2), *Defining Appropriation Issues* (CP6), and *Milestones* (CP7), and *Doing them Jointly* (MAPP4, MAPP5). Also, *Jointly Agreeing on Financial Resources* seems to be an important activity to have a better performance schedule. In terms of communication, the only PMSF in this group is related to *Having Pre-defined Communication Strategies* (EC3). Therefore, after excluding the PMSF related to *Formal review cycles* (PM1), which also had a critical and significative correlation, all the success focuses on definitions that start before the execution of the project.

5.3.3 Budget Performance Measure

Almost 53% of the projects were evaluated above the rating 3, which means that the cost of the project was the same as the budget or below. However, the mean of this measure in each knowledge source sample was below 3. The highest mean was for projects with Science-based knowledge source (2.7).

The correlation results in this measure presented critical and significant correlation only for the Both-based source sample. More specifically, *Having A Formal Review Cycle* (PM1) affects *Budget Performance* in projects carried out with both types of sources. Additionally, the same effect occurs when the participants have the Perception of *Realistic Project Aims* (CP8).

When we verify these PMSFs in the ranking of the group that had *The Best* performance measure we find that they were evaluated above 4 (agreeing with its presence in the project) and were more used by projects with *The Best* results than by *The Rest*. Also, PM1 was that which received the highest evaluation in *The Best* group.

5.3.4 Patent Performance Measure

R&D outputs (*Patents and Scientific Publications*) achieved, for Science-based and Both based sources, results similar to other company projects. Almost 80% of the whole sample answered that they achieved better or similar results in *Patents* in comparison to other company projects (the same or very near to 80% occurs for both sample and Science-based samples).

Regarding R&D outputs, the only performance measure that had a positive and significant correlation to a PMSF is the *Patents* measure. In this case, *Having Expectations of Discussions with all Partners* (CP1) positively ($r=0.67$; $p<0.01$) affects the patent performance of the projects made with both types of knowledge sources. No other PMSF presented critical and significant correlations to *Patent Performance*.

5.3.5 Comparing PMSFs by Knowledge Sources

It is interesting to compare the PMSFs that had critical correlations by knowledge source as most of them are different. Figure 5.25 shows all the success factors that were significantly correlated to at least one type of performance measure. We can see that almost all success factors evaluated do not have the same correlation by knowledge sources. This suggests that the success factors in project management are contingent to the type of knowledge source, as proposed in Hypothesis 1: *The effect of project management success factors in collaborative R&D project performance is different regarding the external knowledge source involved in the project.*

Figure 5.25 - Success factors that have significant correlation to performance by main theme

	Code	Science-based	Market-based	Both	Code	Science-based	Market-based	Both	
CLEAR PLANNING	CP1	X			PM1		X	X	PROGRESS MONITORING
	CP2		X		PM2				
	CP3				PM3				
	CP4	X			PM4				
	CP5	X	X		EC1				EFFECTIVE COMMUNICATION
	CP6		X		EC2				
	CP7		X		EC3		X	X	
	CP8				EC4				
MUTUALLY AGREED PROJECT PLANS	MAPP1				EC5	X		X	
	MAPP2				EC6				
	MAPP3				EC7				
	MAPP4		X		EC8				
	MAPP5		X		EC9	X		X	
	MAPP6	x							
	MAPP7		X						

Source: Elaborated by the Author

Evaluating the success factors by their main theme as presented in Figure 5.25, we can notice that, in the *Progress Monitoring* theme, there is no correlation of success factors with projects made with Science-based knowledge sources. In *Clearly Planning Issues* only one success factor is significantly and critically correlated to Science-based and Market-based knowledge sources. Here, there are other correlations for each type of source, but they are not the same. In the case of *Mutually Agreed Project Plans*, all success factors are different between sources. And, for *Effective Communication* there are only cases where a success factor is significant and critically correlated to Both-based and one of the two other types.

Moving forward in evaluating the differences between the sources, we present Figure 5.26, in which we add the description of the success factors where there is significant and critical correlation. In general, when evaluating the content of success factors that are correlated to projects made with Science-based sources, it can be seen that they are not so focused on process as are projects made with Market-based sources. For example, while in projects with Science-based sources it is important to encourage informal communication and use joint

problem-solving tasks, in projects made with Market-based sources it is important to have pre-defined communication strategies and use a formal review cycle with fixed time-frames.

Figure 5.26 Description of success factors that have significant correlation to performance by main theme

	CLEAR PLANNING					EFFECTIVE COMMUNICATION				
	Code	Science-based	Market-based	Both		Code	Science-based	Market-based	Both	
MUTUALLY AGREED PROJECT PLANS	CP1	Expectation discussion			PROCESS MONITORING					
	CP2		Sources of conflict discussion			PM1		Formal review cycle with fixed time-frames		
	CP4	Definition of objectives								
	CP5	Definition of responsibilities								
	CP6		Definition of appropriation issues							
	CP7		Definition of milestones							
	MAPP4		Agreement of appropriation issues			EC3		Clearly pre-defined communication strategies		
	MAPP5		Agreement of projects milestones			EC5	Encouraging informal communication		Encouraging informal communication	
	MAPP6	Agreement of technical characteristics of human resources								
	MAPP7		Agreement of financial resources			EC9	Using joint problem-solving tasks		Using joint problem-solving tasks	

Source: Elaborated by the Author

5.4 Control Variables

Regarding control variables, there is no statistically significant difference in the frequency distribution of each variable between the knowledge sources samples. This can be justified by the p results of the Chi-Square test, as there is no $p < 0.01$ (Table 5.12). Therefore, we have evidence to believe that the significant correlations found must be due the relationship between the knowledge sources and the PMSFs.

Table 5.12. Chi-Square test between control variables and knowledge sources samples

Control Variable	Categories	Knowledge source			Total	Chi-square test p
		Both	Market	Science		
Project Complexity	<=2	8 (22)	14 (38)	15 (41)	37	0.403
	>=3	6 (38)	6 (38)	4 (25)	16	
Previous link	both	6 (60)	2 (20)	2 (20)	10	0.088
	no	4 (22)	6 (33)	8 (44)	18	
	yes	4 (16)	12 (48)	9 (36)	25	
Market sector	Aerospace & Defense	0 (0)	1 (100)	0 (0)	1	0.289
	Agribusiness	2 (50)	2 (50)	0 (0)	4	
	Automotive	1 (14)	4 (57)	2 (29)	7	
	Biotechnology	1 (33)	1 (33)	1 (33)	3	
	Chemical	0 (0)	3 (50)	3 (50)	6	
	cosmetics	1 (33)	1 (33)	1 (33)	3	
	Diversified	0 (0)	1 (50)	1 (50)	2	
	Energy	2 (67)	0 (0)	1 (33)	3	
	Healthcare	0 (0)	2 (67)	1 (33)	3	
	Industrial Automation	1 (100)	0 (0)	0 (0)	1	
	NA	1 (12)	1 (12)	6 (75)	8	
	Pharmaceutical	1 (17)	2 (33)	3 (50)	6	
	Service	4 (67)	2 (33)	0 (0)	6	
Governance Mode	Outsourcing	no	11 (26)	14 (33)	17 (40)	0.324
		yes	3 (27)	6 (55)	2 (18)	
	Contract Research	no	10 (23)	17 (39)	17 (39)	0.377
		yes	4 (44)	3 (33)	2 (22)	
	Research Grant	no	11 (24)	19 (41)	16 (35)	0.348
		yes	3 (43)	1 (14)	3 (43)	
	Joint Research Project	no	7 (30)	9 (39)	7 (30)	0.740
		yes	7 (23)	11 (37)	12 (40)	
	Research Consortium	no	10 (20)	20 (41)	19 (39)	0.0024
		yes	4 (100)	0 (0)	0 (0)	
Phase of project	Basic research	no	13 (93)	20 (100)	17 (89)	0.3499
		yes	1 (7)	0 (0)	2 (11)	
	Exploratory research	no	9 (64)	17 (85)	16 (84)	0.2736
		yes	5 (36)	3 (15)	3 (16)	
	Applied research	no	3 (21)	11 (55)	8 (42)	0.1476
		yes	11 (79)	9 (45)	11 (58)	
	Development	no	10 (71)	10 (50)	14 (74)	0.2448
		yes	4 (29)	10 (50)	5 (26)	
	Product improvement	no	11 (79)	17 (85)	18 (95)	0.3814
		yes	3 (21)	3 (15)	1 (5)	

Correlation is Significant at the level <0.01

Source: Elaborated by the Author

6. DISCUSSION

In this study, we explored the effect of *Project Management Success Factors* on project *R&D Performance* for projects carried out with external partners. The analysis was conducted by comparing samples with two types of knowledge sources (Science-based and Market-based partners), which also included a sample with both types. By examining correlation results from the survey data, we found support for the main hypothesis (H1). This hypothesis proposed a different relationship between *Project Management Success Factors* and *R&D Performance* when the *Knowledge source* is considered a moderate variable. More specifically, we identified PMSFs that influence the performance measure, according to the knowledge source involved in the project. We argue that this finding can be explained by the existence of deep dissimilarities between knowledge sources (Estrada, Faems, Martin, et al., 2016) that need to be considered when choosing which *Project Management Success Factor* to emphasize. What is new in this finding is that it allows for a detailed exploration of the success factors and not a broad view of project management. By doing this, we can help to shed light on the discussion of the use of the traditional project management approach in open innovation projects (Du, Leten, & Vanhaverbeke, 2014; Lippe & vom Brocke, 2016). Our research supported, at project level, the proposal of Barnes et al (2006) that certain factors would prove more critical in some types of collaboration than others, as a result of the very different purposes, circumstances and characteristics of each type.

Previous research evaluated differences in financial performance of projects made with Science-based and Market-based knowledge source (Du et al., 2014). Their research specifically considered *Formality* in use of *Progress Monitoring* activities as independent variable. Differently, by including a list of *Project Management Success Factors* and different performance measures, we opened out a new discussion. More specifically, our findings led us to conclude that the differences of the effect of project management in performance in R&D collaborative projects made with Science-based and Market-based sources are much greater than merely in terms of level of formality. The type of success factors that affect each type of project (made with Market-based or Science-based sources) is different. We can argue that projects made with Science-based sources have more result-oriented success factors, like *Encouraging Informal Communication*, *Joint Problem-solving Tasks* and *Discussion of Expectations*, while projects made with Market-based sources have more process-oriented factors, like *Clearly Defining Communication Strategies* and *Formal Review Cycles with Fixed*

Time-frames. Here, again, we rely on the discussion about dissimilarities between these two types of knowledge sources to explain this difference. Science-based sources have different mission, goals, routines, resources, time horizons in relation to Market-based ones (Estrada, Faems, Martin, et al., 2016). While the literature posit that new roles adopted by Universities and also the interest of Market-based sources in accessing scientific network may facilitate the collaboration process (Bjerregaard, 2010), a contingent approach in *Project Management* considering the most suitable approach toward the knowledge source involved in the project, would help increase success of the R&D projects.

While it is expected that communication has a positive effect on the success of cooperative agreements (Mora-Valentin et al., 2004), our research shows that the type of communication strategy used at project level should consider the type of knowledge source in order to improve performance. Prior literature suggests that some special attention to communication in projects with heterogeneous partners should be taken (vom Brocke & Lippe, 2015) and provide some guidelines, like *Having Continuous And Open Balanced Communication* to ensure that the staff understand the “big picture”, *Having a Clear Communication Strategy* that includes the forms of written communication to be used, *Maintaining Strong Informal Communication*, and *Fostering Face-to-face Meetings*, especially in teams that are located in different geographical areas. However, the findings of our study suggest that the guidelines should be adapted to the type of knowledge source involved in the project and not just provide a broad guideline for heterogeneity. More specifically, we suggest that *Pre-Defined Communication Strategies* are suitable for projects made with Market-based partners but not with Science-based ones. On the other hand, *Informal Communication* and *Joint Problem-solving Tasks* should be encouraged with Science-based sources and in projects with both types of sources, but this seems not to affect performance in projects made with Market-based sources.

Planning activities is an essential step in project management. In collaborative projects with external partners, a clear and common agreed definition of objectives, responsibilities and the whole project set-up has been shown to have “a positive influence on the involvement and commitment of partners within a collaborative project” (Barnes et al., 2002, p. 399). This safeguards them from misunderstandings during the project evolution due to the misalignment of partners’ objectives and the low commitment of partners, especially in projects that involve partners from different backgrounds (Morandi, 2013). Our findings support this view, showing that *Clear Planning* and *Mutually Agreeing on Plans* were proportionally the themes with most

success factors with critical correlations to performance. However, certain success factors seem to be more critical in projects made with one or another knowledge source.

Showing that the effect of success factors presence on performance might vary by type of measure and, and that also by knowledge source type, we develop the findings from previous literature (Schwartz et al., 2012). These authors showed that university involvement has a positive effect on project innovation output in terms of the number of publications but not in terms of patent application. Conversely, they demonstrated that large firm involvement is strongly positively related to the number of patent applications, but not to the number of publications. Our findings add a new level of analysis to this relation. Although no correlation was found between PMSFs and patents or publications with Science-based and Market-based sources, we identified that projects with the best results in *Patents* in the Science-based group were those that used more PMSFs related to *Effectiveness of Communication*. In the case of *Publications*, it is of interest to observe that projects with the worst results used more activities related to *Progress Monitoring*. In the same path, we can notice that in the group with the lowest results in *Patents* and *Publications* in projects made with Market-based sources, some PMSFs were used more than in the group with the best results, like *Having Formal Review Cycles with Fixed Time-frames*.

7. CONCLUSIONS AND IMPLICATIONS

Our study contributes to innovation management literature in different ways. Firstly, it strengthens the integration of certain literature streams: project management literature, open innovation, and innovation management. There is an increasing concern about a contingent view in project management, in which open innovation is a field that brings new challenges that need to be faced (Gesing et al., 2015). One of them is the heterogeneity of partners, which might enhance the complexity of management due the dissimilarities between partners (Estrada, Faems, Martin, et al., 2016) and the literature has been examining these challenges mainly at firm level (Chesbrough et al., 2014).

Furthermore, Innovation Management scholars have traditionally tried to identify relationships between several variables and innovation performance. We followed this tradition by incorporating into it the open innovation challenge, which includes working with partner heterogeneity in the context of innovation. More specifically, we open the black box of project management to discuss its success factors and its relation to certain performance measures. However, we add project performance measures to evaluate the success of an R&D project due to the trend for the modern R&D function to be more responsive to organizational needs, which also involves delivering projects on time and within budget (Henttonen et al., 2016). By doing this, we also contribute to the discussion on evaluating project management success factors by relating them to R&D success in collaborative projects as our results suggest that success varies according to the type of performance measured. This might be a second contribution.

Finally, we advance the literature by identifying specific project management success factors that affect performance in R&D collaborative projects. We therefore recognized the dissimilarities that previous literature demonstrated (Bruneel et al., 2010; Estrada, Faems, Martin, et al., 2016) and agree with the evidence that the knowledge source involved in open innovation project should be a contingent factor in project management (Du et al., 2014), but, more specifically, we helped to clarify information on collaborative R&D project management with dissimilar partners by providing evidence of success factors that are dominant in a certain type of project characteristic, in terms of knowledge source involved.

A practical implication of this study is to help managers involved in collaborative R&D to understand which are the success factors that are more suitable according to external partners involved in the project.

8. LIMITATIONS AND FUTURE STUDIES

While certain studies are concerned about the effect of carrying out R&D projects with external partners, there is also a need to have a more fine-grained discussion on how these projects are being managed. It is not enough to know that dissimilarities between partners should be a concern when managing R&D projects with external partners. It is important to identify what approach should be used to overcome dissimilarities challenges and truly take advantage of a collaboration for innovation. Therefore, a great number of research opportunities appear in this context. Specifically, in relation to our findings, we suggest evaluating the use of each success factors in the following ways: examining more detailed data about the characteristics of the project management activity execution; examining diverse performance measures; and examining diverse cultural, industrial and other contexts. In general, the opportunity involves bringing traditional management approaches to the context of Open Innovation, which prior research has already emphasized (Du et al., 2014) but is still underdeveloped.

Some limitations of this study are mainly related to the methodology. The study used an exploratory quantitative approach, which does not allow us to generalize the findings. This also brings the opportunity to move forward in terms of the insights that this study provides. We highlight the opportunity to have a more focused research on the PMSFs that presented critical correlations in our results. It would also be interesting to make this study inside a specific company as it would provide better evidence in terms of patents and publications. This was a limitation in our study as we could not compare the absolute number of patents and publications due to the very different contexts in our sample.

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APPENDIX A – *Collaboration in R&D and Performance* literature review

Reference	Variables	Level of analysis	Findings	Methodology
Aschhoff and Schmidt (2008)	The effect of past R&D cooperation on the current innovation performance of firms.	Firm	R&D cooperation with competitors leads to greater cost reductions that are attributable to innovative processes. R&D cooperation with research institutes has a positive influence on a firm's economic success with market novelties.	Quantitative
Baba, Shichijo, & Sedita (2009)	The effect of university-industry collaborations on the innovative performance of firms	Firm	Pasteur scientists increases firms' R&D productivity, measured as number of registered patents. By contrast, firms' collaboration with "Star scientists" exerts little impact on their innovative output.	Quantitative
Belderbos, Carree and Lokshin (2006)	The performance effects of simultaneous engagement in R&D cooperation with different partners.		The results suggest that the joint adoption of cooperation strategies could be either beneficial or detrimental to firm's performance, depending on firm size and specific strategy combinations.	Quantitative
Belderbos, Faems, Leten, and Van Looy (2010)	The impact of firms' technological strategies on their financial performance.	Firm	This study's analyses confirm the existence of an inverted U-shape relationship between the share of explorative technological activities and financial performance.	Quantitative
Berchicci (2013)	This paper examines the influence of R&D configuration on innovative performance and the moderating role of a firm's R&D capacity	Firm	The findings suggest that firms that increasingly rely on external R&D activities have a better innovative performance, yet up to a point. The opportunity cost for further opening up R&D borders is higher for firms with a superior technological knowledge stock.	Quantitative

APPENDIX A – Collaboration in R&D and Performance literature review - Continued

Reference	Variables	Level of analysis	Findings	Methodology
Carson, Madhok, Varman, and John (2003)	Trust-based governance and task performance.	Firm	Trust-based governance has a larger positive impact on task performance when the client is more skilled at understanding the outsourced tasks at hand.	Quantitative
Chang (2003)	Relationship between inter-organizational co-operation and innovative performance at the firm level.	Firm	The result reveals that the types of inter-organizational co-operation enhancing a firm's innovative performance vary across sectors and countries.	Quantitative
Davis and Eisenhardt (2011)	Rotating leadership and collaborative innovation	Firm	High-performing collaborative innovation involves dynamic organizational processes associated with collaboration partners' leadership roles.	Qualitative
Duysters and Lokshin (2011)	Impact of alliance portfolio complexity measure on firm's innovative performance.	Firm	Alliance complexity is found to have an inverse U-shape relationship to innovative performance.	Quantitative
Frenz and Ietto-Gillies (2009)	Knowledge sources and their impact on the innovation performance of enterprises.	Firm	Interaction between the self-generation of knowledge and external sources increases the innovation potential of enterprises.	Quantitative
Grimpe and Kaiser (2010)	R&D outsourcing and innovation performance	Firm	Inverse U-shaped relationship between R&D outsourcing and innovation performance.	Quantitative
Huang and Yu (2011)	The joint impact of competitive and non-competitive R&D collaborations on firm innovation simultaneously.	Firm	R&D collaboration, either non-competitive or competitive, exhibits the nature of a win-win situation. The positive moderating effect is higher for non-competitive R&D collaboration than that for competitive R&D collaboration.	Quantitative

APPENDIX A – *Collaboration in R&D and Performance* literature review - Continued

Reference	Variables	Level of analysis	Findings	Methodology
Kang and Kang (2010)	The effect of R&D collaboration with each type of partner on product innovation.	Firm	Results show that R&D collaborations with customers and universities have a positive effect on product innovation, whereas R&D collaborations with suppliers and competitors have an inverted-U shape relationship with product innovation.	Quantitative
Kuen-Hung and Wang (2009)	The impact of the strategies of low- and medium-technology (LMT) on firm's innovation performance.	Firm	Inward technology licensing does not contribute significantly to innovation performance. By collaborating with different types of partners, firms with more internal R&D investment gain higher innovation returns than firms with fewer internal R&D activities.	Quantitative
Laursen and Salter (2006)	Search strategy and Innovative performance.	Firm	Searching widely and deeply is curvilinearly (invested U-shape) related to performance.	Quantitative
Lin, Wu, Chang, Wang and Lee (2012)	Related the proportion of R&D alliances in an alliance portfolio, technological distance, and R&D intensity to Innovation performance.	Firm	R&D alliances are more suitable than other types of partnerships to Innovation Performance.	Quantitative
Lokshin, Hagedoorn, and Letterie (2011)	Assess the impact of 'bumpy road' (undesired outcomes) on innovative performance.	Firm	Engagement in partnerships is beneficial for innovative performance. However, firms that experienced a 'bumpy road' in their technological partnerships have to pay a price in terms of a negative effect on their innovative performance.	Quantitative

APPENDIX A – Collaboration in R&D and Performance literature review - Continued

Reference	Variables	Level of analysis	Findings	Methodology
Okamuro (2007)	This paper analyses the impact of the organizational and contractual characteristics of cooperative R&D.	Firm	Cooperative R&D is more successful when there is higher quality and quantity of external resources available through cooperation, and there are lower transaction and coordination costs required for such arrangements.	Quantitative
Petruzzelli (2011)	Effect of Technological relatedness, prior collaboration ties, and geographical distance on innovative performance of R&D.	Firm	Results suggest that partners' technological relatedness has an inverted U-shaped relationship with innovation value. In addition, prior ties and geographical distance between universities and firms are both positively related to the achievement of higher innovative outcomes.	Quantitative
Sampson (2007)	The impact of partner technological diversity and alliance organizational form on firms' innovative performance.	Alliances	Alliances contribute far more to firm innovation when technological diversity is moderate, rather than low or high. Alliance organizational form is likely to influence partner ability and incentives to share information, and this affects performance.	Quantitative
Schmiedeberg (2008)	Related Internal R&D, R&D contracting, and R&D cooperation to firm sales and patenting.	Firm	The results provide evidence for significant complementarities between internal R&D and R&D cooperation, but cast doubt on the complementarity of internal and contracted R&D.	Quantitative
Shrader (2001)	Collaboration and performance in foreign markets.	Firm	Results indicated that R&D intensity and advertising intensity were significant moderators of this relationship. However, they were not significantly related to the use or nonuse of collaboration.	Quantitative

APPENDIX A – *Collaboration in R&D and Performance* literature review - Continued

Reference	Variables	Level of analysis	Findings	Methodology
Schwartz, Peglow, Fritsch and Guenther (2012)	Project characteristics and innovation output.	Projects	Large-firm involvement is strongly positively related to the number of patent applications, but not to the number of publications. Conversely, university involvement has positive effects on projects' innovation output in terms of the number of publications but not in terms of patent applications.	Quantitative
Un, Cuervo-Cazurra and Asakawa (2010)	Impact on product innovation of research and development (R&D) collaborations with universities, suppliers, customers, and competitors.	Firm	The tests find that R&D collaborations with suppliers have the highest positive impact on product innovation, followed by collaborations with universities. The paper is one of the first to theoretically explain and empirically show that various types of collaborations have a differential influence on product innovation.	Quantitative

APPENDIX B – Classification of variables

Variable	Dimension	Items
R&D performance (dependent)	R&D Output	Patent application or grants
	R&D Output	Scientific publications
	R&D Output	Overall R&D output success
	Project Management	Budget (actual cost versus budget)
	Project Management	Schedule (actual versus plan)
	Project Management	Quality (Technical quality of project execution)
Project management activities (independent)	Clearly planned issues	Expectations of all partners were discussed
	Clearly planned issues	Possible sources of conflict were discussed involving all partners
	Clearly planned issues	The collaborative agreement was simple to understand
	Clearly planned issues	The objectives were clearly defined
	Clearly planned issues	The responsibilities of all parties were clearly defined
	Clearly planned issues	The appropriation issues were clearly defined
	Clearly planned issues	The project milestones were clearly defined
	Clearly planned issues	The project aims were realistic
	Mutually agreed project plan	The objectives were mutually agreed
	Mutually agreed project plan	The responsibilities were mutually agreed
	Mutually agreed project plan	The appropriation issues were mutually agreed
	Mutually agreed project plan	The project milestones were mutually agreed
	Mutually agreed project plan	The technical characteristics of the human resources for the project were mutually agreed
	Mutually agreed project plan	The financial resources need for the project were mutually agreed
	Mutually agreed project plan	The collaborative agreement was mutually discussed
	Process monitoring	A plan - execution – review cycle with fixed time frames was used
	Process monitoring	During project reviews, corrective actions, to make sure the project proceeded according to the project plan, were conducted.
	Process monitoring	During project reviews, corrective actions, to make sure the project proceeded according to the project plan, were discussed with all partners.
	Process monitoring	During project reviews, if any new information was presented (like an opportunity unpredicted), some flexibility in project plan was allowed.
	Process monitoring	Joint problem-solving tasks were conducted to facilitate the use of collective competence.

APPENDIX B – Classification of - Continued

Variable	Dimension	Items
Project management activities (independent)	Effective communication	Training in collaborative work and inter-cultural awareness was provided
	Effective communication	There was continuous and open communication that helped the staff understand the overall objective of the project and all the achievements
	Effective communication	Communication strategies between parties, like forms of communication to be used and frequency of meetings, were clearly defined.
	Effective communication	Face to face meetings were an important form of communication during the project
	Effective communication	Informal communication was encouraged
	Effective communication	A common template/framework to share the overall project information (like main objectives, project evolution, project phases) was used.
	Effective communication	The communication between the company and the partner was centralized
Moderating variable	Effective communication	Employee exchange program between the partners was an important form of knowledge integration
	Knowledge Source	University; Public Research Institute; Startup Company; Competitor Company; Other Supplier Company; Consultant/Individual actor; Private R&D Institute.
	Complexity of the project	Number of external partners involved in the project.
	Duration of the project	Duration of the Project
	Previous link	If it was the first R&D project made with this partner.
	Geographical Proximity	Location of the partners
	Governance Mode	Outsourcing; Contract Research; Research Grant; Joint Research Project; Research Consortium; Joint Lab or Incubator Concept; Joint Venture.
Control variables	Level of Uncertainty	Basic Research; Exploratory Research; Applied Research; Development; Product Improvement.

APPENDIX B – Classification of variables - Continued

Variable	Dimension	Items
Qualitative data (describing the sample)	Industry sector	(Open ended question)
	Country of the respondent	(list of countries)
	Country of the company headquarters	(list of countries)
	Company Size	(Open ended question)
	Number of employees in R&D	(Open ended question)
	R&D investment	(Open ended question)
	Company with Open Innovation structure	Yes/no
	Type of Open Innovation activity	Partner/search; IP and License; Contract and legal; Technology transfer; Dedicated partnership management
	Number of projects the respondent has per year	(Open ended question)

APPENDIX C – Research Instrument

INSTRUCTIONS

This survey collects information about R&D collaborative projects and its management aspects. It is part of a PhD thesis in the Innovation Management field developed at the School of Economics, Administration and Accountancy of the University of São Paulo.

You should only consider one project when answering the questionnaire. If you answer on more than one project, please fill in the questionnaire separately for each project. Please remember that this is not a questionnaire related to general practice of your company but rather to the specific project you choose.

The R&D project considered for this research project should have been carried out with at least one external partner. Please consider projects that were finalized within the past 36 months.

Section 1 asks for general information about the project. Section 2 refers to project performance. Section 3 requests information about project management issues. And the last section deals with characteristics of the company.

Please complete all the questions. If you have any doubts regarding this questionnaire send an email to afleme@gmail.com.

The survey will take about 20 minutes to answer.

Your company might have some R&D projects using general practices, but please do not give general information. Please give the project a name (fictional or not).

I. GENERAL INFORMATION ABOUT THE PROJECT

1. Give a name to the project you are considering using in this questionnaire (for example, Project A; Project B or choose your own name(s))

2. What type of R&D project is this?

Product modification

New generation of an existing product

New product or process for the partners

New product or process for the industry

3. What type of partner was involved in the project?

University

Public Research Institute

Startup company

Competing company

Other supplier company

Consultant / individual actor
 Private R&D institute
 Other (please specify)

4. How many external partners were involved in the project?

1 2 3 4 5 6 7 8 9 10 or more

5. Was it the first project conducted together with this (or these) partner(s)?

a. Yes, this is the first time we made a partnership with this (these) partner(s)

b. No, we have already made other projects with this (these) partner(s)

c. In this project, we had both a partner that was developing a project with the company for the first time and a partner that had performed projects with us before.

6. How long did this project take?

1 year or less

2 years

3 years

4 years

5 years

More than 5 years

7. Where is the partner located? (You should consider the team that was involved in the project. In the case of more than one partner, consider where the majority are located)

a. Same city

b. Same country, but not the same city

c. Another country in the same continent

d. Another country in another continent

8. What was the type of relationship established with the partner?

a. Outsourcing (contractual supply of results of separate tasks)

b. Contract Research (supply of results of basic / fundamental research or multiple tasks including IP rights)

c. Research Grant (receive or provide funding for specific research direction with less formal confidentiality or IP agreements)

d. Joint research project (collaboratively initiated mutual research between two parties, also as part of long-term collaboration agreements)

e. Research Consortium (research or new technological developments initiated between multiple parties, which can include private and non-private organizations)

f. Joint lab or incubator concept (two or more parties have created joint lab space, or one party resides in the research facilities of another party for a defined period / task)

g. Joint-Venture (organizational units created and controlled by two or more parent-companies)

h. Other (please specify)

9. What type/phase of R&D project was it?

- a. Basic research (directed to the search for fundamental knowledge)
- b. Exploratory research (to determine whether a certain scientific concept might have useful application)
- c. Applied research (directed to improving the practicality of a specific application)
- d. Development (engineering improvement of a particular product or process)
- e. Product improvement (directed to changes in a product or process that can increase its marketability, reduce its costs, or both).

II. INFORMATION ABOUT PROJECT PERFORMANCE

10. How many patent applications did this project generate?

11. Was this number of patent applications better or worse than that which other projects in your company with external partners have generated?

- a. Better
- b. Worse
- c. The same

12. How many scientific publications in peer-reviewed journals were generated by this project.

13. Was this number of scientific publications in peer-reviewed journals better or worse than that which other projects in your company with external partners have generated?

- a. Better
- b. Worse
- c. The same

14. Please give information on the Budget Performance of the project (actual cost versus budget).

- a. The actual cost overran the budget by more than 10%
- b. The actual cost overran the budget by 5% to 10%
- c. The actual cost overran budget by less than 5%
- d. The actual cost was the same as the budget
- e. The actual cost was below the budget by less than 5%
- f. The actual cost was below the budget by 5% to 10%
- g. The actual cost was below the budget by more than 10%
- h. The project does not have a defined budget

15. Give information of the Schedule Performance (actual versus plan)

- a. late finish by more than 10%
- b. late finish by 5% to 10%

- c. late finish by less than 1 to 5%
- d. finished on time
- e. early finish by less than 1 to 5%
- f. early finish by 5% to 10%
- g. early finish by more than 10%

16. Indicate a score from 0 to 5 to evaluate the technical quality of project execution. 0 = expectation not met; 5 = exceeded expectation

17. Indicate a score from 0 to 5 to evaluate the overall project success in terms of R&D output generated (R&D output is defined as actual results that the R&D project achieved).

III. PROJECT MANAGEMENT ACTIVITIES

In this section please give information about project management activities during the project.

18. On a scale from 0 to 5, where 0 is strongly disagree, and 5 is strongly agree, what score would you use to rate each of the practices in this project.

	0	1	2	3	4	5
Expectations of all partners were discussed						
Possible sources of conflict were discussed involving all partners						
The collaborative agreement was simple to understand						
The collaborative agreement was mutually discussed with all partners						
The objectives of the project were clearly defined						
The objectives of the project were mutually agreed with all partners						
The responsibilities of all parties were clearly defined						
The responsibilities of each partner were mutually agreed with all partners						
The appropriation issues were clearly defined						
The appropriation issues were mutually agreed with all partners						
The project milestones were clearly defined						
The project milestones were mutually agreed with all partners						
The project aims were realistic						
The technical characteristics of the human resources for the project were mutually agreed with all partners						

The financial resources needed for the project were mutually agreed with all partners						
A plan / execution / review cycle with fixed time-frames was used						
During project reviews, corrective actions, to make sure the project proceeded according to the project plan, were conducted.						
During project reviews, corrective actions, to make sure the project proceeded according to the project plan, were discussed with all partners.						
During project reviews, if any new information was presented (like unpredicted opportunities), some flexibility in project plan was allowed.						
Joint problem-solving tasks were conducted to facilitate the use of collective competence.						
Training in collaborative work and inter-cultural awareness was provided for the team involved in the project.						
There was continuous and open communication that helped the staff understand the overall objective of the project and its achievements						
Communication strategies between partners, like forms of communication to be used and frequency of meetings, were clearly defined.						
Face-to-face meetings were an important way of communication during the project						
Informal communication was encouraged						
A common template/framework to share the overall project information (like main objectives, project evolution, project phases, main challenges) was used.						
The communication between the company and the partner was centralized (should be made by one person in each team)						
An employee exchange program between the partners was an important form of knowledge integration						

IV. INFORMATION ABOUT THE COMPANY AND THE RESPONDENT

19. Which is the market sector of the company?

20. How many employees work at your organization?

21. How many employees are there in R&D?

22. How much was the R&D investment in 2016 (US\$)?

23. Does the company have a dedicated unit to facilitate open innovation / partnerships?

YES

NO

24. If you answered 'yes' in the previous question, indicate which type of activity this unit supports (select all that apply).

a. Partner search /scouting

b. IP and license support

c. Contracting and legal support

d. Technology transfer

e. Dedicated partnership manager

f. Other (please specify)

25. Inform your job title

26. How many projects do you (as a R&D or partnering manager) have per year?

27. Please provide an email address so we can share the survey feedback and consolidated results with you and in case we have questions regarding the answers you have sent.

28. What is the name of the company? (optional)

29. In which country do you work?

30. In which country is your company's headquarters?

APPENDIX D – Summary of the correlation table

Market-based sources					Science-based sources					Both-based sources						
Variables		Technical quality			Overall			Technical quality			Overall			Technical quality		
Patent	Publication	Budget	Schedule	Overall	Patent	Publication	Budget	Schedule	Overall	Patent	Publications	Budget	Schedule	Overall		
CP1	0.17	0.07	0.3	0.38	0.1	-0.19	0.01	0.14	0.39*	0.79***	-0.1	0.42	0.37	0.44	0.25	
CP2	-0.11	0.02	0.45*	0.71***	0.23	-0.13	-0.18	0.21	0.4*	0.48**	-0.05	-0.25	0.47*	0.59**	0.35	
CP3	-0.28	-0.12	0.09	0.5**	0.04	0	-0.29	0.4*	0.17	0.3	0.38	0.05	0.25	0.37	0.41	
CP4	0.20	-0.06	0.13	0.49**	0.28	0.15	-0.25	0.02	0.29	0.65***	-0.03	0.04	0.1	0.07	0.23	
CP5	-0.30	-0.33	0.34	0.76***	0.15	0	-0.08	0.11	0.38*	0.62***	0.02	0.06	0.04	0.09	0.06	
CP6	-0.20	-0.13	0.13	0.61***	0.13	0.08	-0.3	0.13	0	0.28	0.3	-0.31	0.16	-0.02	0.06	
CP7	-0.08	-0.18	0.46**	0.6***	0.43*	0.24	-0.12	0.25	0.4*	0.43*	-0.43	-0.06	0.21	0.11	0.14	
CP8	0.00	0.00	0.15	0.51**	0.21	0.24	-0.19	0.18	0.37	0.2	0.3	0.34	0.61**	0.54*	0.13	
MAPP1	-0.08	-0.18	0.19	0.47**	0.18	0.08	-0.29	-0.13	0.28	0.32	-0.01	-0.22	0.24	0.11	0.09	
MAPP2	-0.07	-0.15	0.27	0.42*	0.36	0.35	-0.32	0.02	0.3	0.29	0.1	0.02	0.01	0.17	0.52*	
MAPP3	-0.09	-0.19	0.19	0.53**	0.2	0	-0.16	0.1	0.2	0.36	-0.12	-0.06	0.01	-0.01	-0.02	
MAPP4	-0.22	0.00	0.19	0.68***	0.16	0	-0.27	-0.01	0.16	0.22	0.35	-0.2	0.24	0.1	0.06	
MAPP5	-0.10	-0.11	0.43*	0.67***	0.35	0.08	-0.12	0.25	0.31	0.17	0.12	0.37	0.21	0.18	0.14	
MAPP6	0.39*	0.15	0.28	0.58***	0.26	-0.29	0.06	-0.06	-0.03	0.48**	0.2	-0.21	0.38	0.36	0.21	
MAPP7	-0.02	-0.28	0.16	0.64***	0.04	-0.16	-0.17	0.33	0.48**	-0.11	-0.24	0	0	0	0.18	
PM1	-0.25	-0.2	0.22	0.63***	0.15	0.15	-0.05	0.21	0.38	0.11	-0.29	-0.28	0.68***	0.54*	0.21	
PM2	-0.01	-0.03	0.05	0.54**	0.17	0.13	-0.07	-0.21	0.06	0.08	0.16	-0.08	0.19	-0.05	0.02	
PM3	0.26	0.18	0.13	0.38	0.04	0.07	-0.2	-0.13	0.07	0.28	-0.06	0.11	-0.08	-0.18	0.32	
PM4	0.2	-0.2	0.24	0.4*	0.22	0.08	-0.16	-0.21	0.24	0.19	0.38	-0.33	0.4	0.37	0.41	
EC1	-0.13	0.09	0.25	0.55**	0.17	-0.18	0.09	-0.17	-0.15	0.42*	0.4	0	0	0.16	0.3	
EC2	-0.11	-0.14	0.32	0.59***	0.22	0.08	-0.26	-0.19	0.03	0.44*	0.18	0.07	0.52*	0.49*	0.53**	
EC3	-0.03	-0.07	0.25	0.71***	0.25	0	-0.1	0.01	0.13	-0.11	0.3	0.27	0.35	0.32	0.41	
EC4	-0.08	-0.1	0.15	0.24	-0.12	-0.19	-0.41*	-0.17	0.23	-0.03	-0.18	-0.07	0.06	-0.1	0.4	
EC5	0.45*	0.09	-0.07	0.25	0.02	-0.32	-0.01	0.12	-0.06	0.35	0.14	0.16	0.41	0.45	0.68***	
EC6	-0.12	-0.18	0.15	0.53**	0.14	-0.07	0.1	0.25	-0.03	0.37	0.25	-0.33	0.34	0.26	0.36	
EC7	0.29	-0.03	0.05	0.51**	0.31	-0.18	-0.08	0.28	0.19	0.45**	0.38*	-0.32	0.28	0.25	0.32	
EC8	0.39*	0.45*	0.24	0.07	-0.08	-0.4	0.34	0.28	0.11	0.54**	0.35	-0.16	-0.03	0.05	0.21	
EC9	0.33	0.19	0.05	0.14	0.04	0	0.08	0.18	0.37	0.16	0.24	0.13	0.29	0.47*	0.71***	

* Correlation is significant at the $p < 0.10$ level; ** Correlation is significant at the $0.05 < p < 0.1$ level;*** Correlation is Significant at the level $p < 0.01$.

APPENDIX E – Correlation Table – All sources

All sources						
Variables	Patent	Publications	Budget	Schedule	Technical quality	Overall
CP1	0.03	-0.07	0.23	0.4***	0.4***	0.21
CP2	-0.12	-0.12	0.36***	0.55***	0.34**	0.08
CP3	-0.15	-0.04	0.24*	0.31**	0.18	0.13
CP4	-0.05	0.01	0.19	0.32**	0.42***	0.24
CP5	-0.12	-0.03	0.25*	0.45***	0.33**	0.2
CP6	-0.09	-0.09	0.21	0.19	0.16	0.05
CP7	-0.18	0.05	0.33**	0.3**	0.36***	0.18
CP8	-0.02	0.12	0.27*	0.38***	0.28**	0.33**
MAPP1	-0.18	-0.16	0.25*	0.33**	0.33**	0.13
MAPP2	-0.13	-0.03	0.24*	0.32**	0.44***	0.34**
MAPP3	-0.12	-0.04	0.21	0.35**	0.31**	0.16
MAPP4	-0.05	-0.1	0.23	0.31**	0.22	0.07
MAPP5	-0.06	0.18	0.3**	0.33**	0.33**	0.16
MAPP6	0.18	-0.01	0.16	0.48***	0.47***	0.1
MAPP7	-0.14	0.12	0.24*	0.12	0.13	0.2
PM1	-0.17	-0.01	0.28**	0.34**	0.26*	0.11
PM2	-0.01	-0.14	0.07	0.2	0.21	0.14
PM3	-0.02	0.01	0.09	0.19	0.23*	0.12
PM4	0.03	-0.24*	0.22	0.26*	0.17	0.17
EC1	0.11	-0.07		0.38***	0.08	0.21
EC2	-0.11	-0.11	0.23*	0.5***	0.4***	0.25
EC3	0.07	0.03	0.18	0.24*	0.26*	0.02
EC4	-0.24*	-0.11	0.14	0.06	0.06	0.08
EC5	0.32**	0.15	0.06	0.33**	0.3**	0.07
EC6	0.08	-0.03	0.12	0.39***	0.27*	0.07
EC7	0.19	-0.02	0.17	0.4***	0.33**	0.11
EC8	0.36***	0.22	0.11	0.24*	0.06	0.13
EC9	0.19	0.18	0.19	0.2	0.28**	0.16

* Correlation is significant at the level <0.10

** Correlation is significant at the level $0.05 < p < 0.1$

*** Correlation is Significant at the level <0.01

APPENDIX F – The Best projects evaluation

Variables	Patent				Publication				Budget				Schedule				Technical				Overall				Standard Deviation					
	Market-based sources	Science-based sources	Both-based sources	All sources	Market-based sources	Science-based sources	Both-based sources	All sources	Market-based sources	Science-based sources	Both-based sources	All sources	Market-based sources	Science-based sources	Both-based sources	All sources	Market-based sources	Science-based sources	Both-based sources	All sources	Market-based sources	Science-based sources	Both-based sources	All sources	Patent	Publications	Budget	Schedule	Technical	Overall
CP1	3.9	3.9	3.8	3.9	3.9	3.8	3.8	3.8	4.2	4.0	4.4	4.1	4.0	4.3	4.4	4.2	3.9	4.1	3.9	4.0	3.5	4.1	4.0	3.9	0.03	0.03	0.12	0.11	0.04	0.19
CP2	3.5	3.6	3.4	3.5	3.6	3.7	3.3	3.5	4.0	4.0	4.0	4.0	4.3	4.2	4.1	4.2	3.7	3.9	3.5	3.7	3.5	4.1	3.5	3.8	0.06	0.10	0.00	0.03	0.12	0.20
CP3	3.8	3.6	4.0	3.8	3.7	3.8	3.8	3.8	3.7	4.1	4.0	3.9	4.3	3.9	4.1	4.1	3.9	3.9	3.9	3.9	4.1	4.1	3.9	4.0	0.10	0.02	0.12	0.10	0.03	0.07
CP4	4.3	4.3	4.2	4.3	4.2	4.3	4.1	4.2	4.2	4.5	4.3	4.4	4.5	4.5	4.3	4.4	4.4	4.5	4.2	4.4	4.4	4.5	4.4	4.4	0.02	0.05	0.09	0.07	0.08	0.06
CP5	3.8	4.2	3.8	4.0	3.8	4.1	3.8	3.9	4.1	4.3	3.8	4.2	4.6	4.4	4.0	4.4	4.1	4.3	3.9	4.1	4.4	4.4	4.0	4.3	0.13	0.12	0.15	0.18	0.12	0.13
CP6	3.7	3.8	3.7	3.8	3.8	4.0	3.3	3.7	3.8	4.2	4.0	4.0	4.3	3.9	3.4	3.9	3.9	4.1	3.5	3.9	4.1	4.0	3.5	3.9	0.02	0.19	0.11	0.22	0.18	0.18
CP7	4.1	3.9	4.0	4.0	4.1	4.0	4.1	4.0	4.3	4.3	4.4	4.3	4.6	4.1	4.1	4.3	4.4	4.1	4.1	4.2	4.6	4.0	4.1	4.2	0.06	0.03	0.04	0.17	0.08	0.20
CP8	4.0	3.7	4.0	3.9	4.0	3.8	3.9	3.9	3.9	4.0	4.3	4.0	4.4	3.9	4.3	4.1	4.1	3.9	3.9	4.0	4.3	4.0	4.0	4.1	0.09	0.05	0.11	0.15	0.06	0.09
MAPP1	4.1	4.0	4.1	4.0	4.0	4.1	4.0	4.0	4.1	4.4	4.4	4.3	4.5	4.5	4.1	4.4	4.3	4.4	4.1	4.3	4.4	4.7	4.1	4.4	0.03	0.05	0.10	0.12	0.09	0.16
MAPP2	4.1	4.2	4.3	4.2	4.1	4.3	4.2	4.2	4.3	4.5	4.2	4.4	4.4	4.5	4.4	4.4	4.4	4.5	4.3	4.4	4.5	4.5	4.5	4.5	0.06	0.04	0.10	0.04	0.07	0.02
MAPP3	4.0	4.2	3.7	4.0	4.0	4.2	3.7	4.0	4.1	4.5	3.8	4.2	4.5	4.5	3.9	4.3	4.2	4.4	3.8	4.2	4.3	4.5	3.9	4.2	0.13	0.15	0.20	0.22	0.18	0.15
MAPP4	3.9	4.0	3.7	3.9	3.9	4.0	3.3	3.8	3.9	4.2	4.0	4.1	4.4	4.2	3.6	4.1	4.1	4.2	3.5	4.0	4.1	4.2	3.5	3.9	0.07	0.21	0.10	0.24	0.22	0.20
MAPP5	3.9	3.9	4.1	4.0	3.9	4.1	4.2	4.0	4.1	4.3	4.4	4.2	4.5	4.1	4.3	4.3	4.1	4.2	4.1	4.1	4.3	4.1	4.2	4.2	0.07	0.09	0.08	0.11	0.01	0.05
MAPP6	3.7	4.1	3.8	3.9	3.7	3.8	3.8	3.7	3.7	4.0	4.2	3.9	4.0	4.4	4.0	4.2	3.7	4.2	3.8	3.9	3.6	4.1	3.7	3.8	0.13	0.04	0.15	0.15	0.15	0.14
MAPP7	3.7	3.5	3.9	3.7	3.6	3.9	3.9	3.8	3.7	4.1	3.8	3.9	4.3	3.6	4.0	3.9	3.8	3.8	4.0	3.9	3.9	3.9	4.2	4.0	0.12	0.11	0.15	0.19	0.06	0.10
PM1	3.7	3.3	4.0	3.7	3.7	3.6	3.9	3.7	3.8	3.8	4.8	3.9	4.5	3.5	4.3	4.0	4.0	3.6	4.0	3.9	4.4	3.5	3.9	3.9	0.19	0.09	0.34	0.33	0.13	0.23
PM2	3.8	3.7	3.9	3.8	3.7	3.5	3.8	3.7	3.4	3.7	4.4	3.8	4.3	3.8	3.7	3.9	3.9	3.9	3.8	3.9	4.1	4.0	3.7	3.9	0.06	0.08	0.28	0.17	0.05	0.12
PM3	4.0	3.9	3.7	3.9	3.9	3.8	3.7	3.8	3.7	4.1	3.8	3.9	4.3	4.2	3.4	4.0	3.9	4.2	3.6	3.9	4.0	4.1	3.8	4.0	0.08	0.07	0.12	0.27	0.14	0.07
PM4	4.1	3.4	4.1	3.8	3.9	3.3	3.8	3.7	4.0	3.7	4.4	3.9	4.4	3.8	4.1	4.0	4.1	3.7	3.9	3.9	4.4	3.8	3.9	4.0	0.23	0.17	0.19	0.18	0.11	0.17
EC1	3.0	3.0	3.3	3.1	3.0	2.7	2.8	2.8	2.9	2.9	3.0	2.9	3.6	3.5	3.4	3.5	3.2	2.9	3.0	3.0	3.1	3.0	3.3	3.1	0.09	0.08	0.03	0.05	0.08	0.07
EC2	3.7	3.9	4.0	3.8	3.6	3.7	3.9	3.7	3.8	4.0	4.4	4.0	4.1	4.3	4.1	4.2	3.9	4.1	3.9	4.0	4.0	4.0	3.9	4.0	0.09	0.08	0.18	0.04	0.08	0.03
EC3	3.5	3.5	3.9	3.6	3.5	3.5	3.8	3.6	3.6	3.6	4.2	3.7	4.1	3.5	3.9	3.8	3.8	3.6	3.6	3.7	3.9	3.7	3.6	3.7	0.14	0.08	0.22	0.18	0.05	0.07
EC4	3.9	3.5	4.2	3.8	3.7	3.7	4.1	3.8	3.9	4.0	4.2	4.0	4.1	3.8	4.0	3.9	3.9	3.9	4.1	4.0	3.8	3.9	4.3	4.0	0.20	0.13	0.09	0.11	0.07	0.15
ECS	3.5	4.1	4.2	3.9	3.3	4.0	3.9	3.7	2.8	4.1	4.4	3.8	3.6	4.4	4.1	4.1	3.2	4.2	3.8	3.8	3.0	4.2	3.8	3.8	0.21	0.21	0.50	0.22	0.27	0.34
EC6	3.3	3.6	3.8	3.5	3.1	3.5	3.3	3.3	3.1	3.6	4.4	3.6	3.9	3.8	3.7	3.8	3.5	3.6	3.5	3.6	4.0	3.2	3.5	3.5	0.15	0.09	0.36	0.05	0.05	0.23
EC7	3.9	3.7	3.7	3.8	3.7	3.7	3.3	3.6	3.7	3.8	4.5	3.9	4.4	4.0	3.7	4.0	4.0	3.8	3.4	3.8	3.9	3.8	3.4	3.7	0.05	0.15	0.27	0.17	0.17	0.17
EC8	2.7	2.8	2.8	2.8	2.7	2.7	2.4	2.6	2.7	3.0	2.8	2.9	2.4	3.5	3.0	3.0	2.4	2.5	2.6	2.5	1.8	2.7	3.0	2.6	0.05	0.11	0.11	0.30	0.07	0.38
EC9	3.9	3.7	4.2	3.9	3.8	3.7	4.1	3.8	3.4	3.9	4.4	3.8	3.8	3.8	4.3	3.9	3.8	3.8	4.0	3.9	3.6	3.8	3.9	3.8	0.12	0.12	0.26	0.17	0.07	0.09

The scale is from 0 to 5.

Ratings shown are those above 4.

Source: Elaborated by the Author

APPENDIX G - Difference between The Best and The Rest

Market-based sources							Science-based sources					Both-based sources							All sources						
Variables	Patent	Publication	Budget	Schedule	Technical quality	Overall	Patent	Publication	Budget	Schedule	Technical quality	Overall	Patent	Publications	Budget	Schedule	Technical quality	Overall	Patent	Publications	Budget	Schedule	Technical quality	Overall	
CP1	0.1	0.1	0.72	0.3	0.6	0.2	0.1	-0.4	0.4	0.9	N/A	-0.9	-0.5	-1.3	0.7	1.0	N/A	N/A	0.0	-0.4	0.6	0.7	1.6	0.7	
CP2	-0.8	-0.2	0.70	1.1	0.4	-0.2	-0.8	-0.5	0.8	0.9	N/A	-0.9	-0.6	-1.2	0.8	1.3	N/A	N/A	-0.8	-0.5	0.8	1.1	1.3	0.4	
CP3	-0.5	-0.8	-0.43	0.6	0.3	0.5	-0.8	0.0	1.1	0.3	N/A	0.1	0.7	-0.8	0.2	0.6	N/A	N/A	-0.3	-0.4	0.2	0.5	1.5	0.8	
CP4	0.3	0.0	0.02	0.5	1.0	1.0	-0.3	-0.3	0.5	0.4	N/A	-0.5	-0.1	-0.9	0.0	0.1	N/A	N/A	-0.1	-0.4	0.2	0.4	1.2	1.2	
CP5	-1.0	-1.0	0.21	1.1	0.4	0.7	0.2	-0.1	0.7	0.7	N/A	1.4	-0.2	-0.8	-0.1	0.3	N/A	N/A	-0.3	-0.5	0.3	0.7	1.4	1.3	
CP6	-0.8	-0.5	-0.22	0.6	0.3	0.8	-0.6	0.2	1.0	-0.1	N/A	-1.0	1.1	-1.2	0.8	-0.1	N/A	N/A	-0.2	-0.4	0.5	0.2	1.1	0.7	
CP7	-0.7	-0.7	0.23	0.7	1.0	1.3	-0.3	0.2	1.3	0.3	N/A	-1.0	-0.7	-0.4	0.4	0.0	N/A	N/A	-0.5	-0.2	0.5	0.3	1.3	1.0	
CP8	0.0	0.0	-0.21	0.6	0.8	1.3	-0.3	0.0	0.8	0.3	N/A	0.0	0.3	-0.1	0.5	0.8	N/A	N/A	0.0	0.0	0.2	0.5	1.3	1.3	
MAPP1	-0.4	-0.8	-0.09	0.6	0.6	1.0	-1.0	-0.5	0.6	0.6	N/A	-0.3	0.1	-0.5	0.5	0.1	N/A	N/A	-0.5	-0.6	0.3	0.5	1.2	1.2	
MAPP2	-0.7	-0.4	0.23	0.3	1.0	1.5	-0.6	-0.3	0.7	0.4	N/A	-0.5	-0.1	-0.8	-0.1	0.3	N/A	N/A	-0.5	-0.4	0.3	0.3	1.0	1.5	
MAPP3	-0.5	-0.5	0.01	0.7	0.5	0.9	-0.2	-0.2	0.9	0.6	N/A	0.5	-0.3	-0.8	0.0	0.1	N/A	N/A	-0.3	-0.5	0.4	0.5	1.5	1.2	
MAPP4	-0.6	-0.3	-0.21	0.6	0.4	0.5	-0.2	-0.2	0.6	0.3	N/A	0.2	1.1	-1.2	0.8	0.1	N/A	N/A	0.0	-0.5	0.4	0.4	0.9	0.7	
MAPP5	-0.6	-0.6	0.21	0.9	0.8	0.9	-0.3	0.3	1.1	0.2	N/A	-0.9	-0.2	0.2	0.4	0.3	N/A	N/A	-0.4	-0.1	0.4	0.5	0.9	1.0	
MAPP6	0.2	0.2	0.07	0.6	0.4	0.0	0.5	-0.8	0.0	1.0	N/A	-0.9	0.2	-0.3	0.6	0.4	N/A	N/A	0.3	-0.4	0.3	0.8	0.9	0.4	
MAPP7	-0.3	-0.9	-0.23	0.8	0.1	0.2	-0.9	0.9	1.7	-0.3	N/A	-1.1	-0.4	-0.6	-0.3	0.0	N/A	N/A	-0.6	0.0	0.3	0.2	1.1	0.6	
PM1	-0.8	-1.1	-0.22	1.0	0.7	1.0	-0.7	0.4	1.2	0.0	N/A	-1.5	0.0	-0.6	1.1	0.6	N/A	N/A	-0.5	-0.3	0.3	0.5	0.9	0.7	
PM2	-0.2	-0.5	-0.76	0.7	0.6	1.1	-0.3	-0.9	-0.1	0.0	N/A	-1.0	0.6	0.3	1.0	-0.1	N/A	N/A	-0.1	-0.5	-0.1	0.2	0.9	0.9	
PM3	0.5	0.2	-0.43	0.6	0.3	1.0	-0.3	-0.8	0.3	0.4	N/A	-0.9	0.4	0.2	0.2	-0.4	N/A	N/A	0.2	-0.3	0.1	0.3	1.1	1.0	
PM4	0.1	-0.6	-0.10	0.6	0.5	1.0	-0.8	-1.1	0.5	0.4	N/A	-1.2	1.1	-0.8	0.8	0.6	N/A	N/A	0.0	-0.8	0.2	0.4	1.1	0.8	
EC1	-0.5	-0.5	-0.41	0.9	0.5	0.1	0.8	-0.5	0.5	1.8	N/A	2.0	1.3	-1.2	0.0	0.9	N/A	N/A	0.5	-0.6	-0.1	1.1	1.1	0.9	
EC2	-0.3	-0.7	0.08	0.7	0.9	0.7	-0.3	-0.9	0.2	0.8	N/A	-1.0	0.7	0.4	0.8	0.6	N/A	N/A	-0.1	-0.5	0.3	0.7	0.8	0.8	
EC3	-0.5	-0.5	-0.14	0.9	0.8	0.5	0.1	0.1	0.6	0.1	N/A	-1.3	1.2	0.8	0.9	0.4	N/A	N/A	0.2	0.0	0.3	0.4	1.3	0.5	
EC4	0.4	-0.8	0.09	0.5	0.6	0.4	-1.3	-0.3	0.8	-0.1	N/A	-1.1	0.2	-0.4	0.1	-0.3	N/A	N/A	-0.3	-0.5	0.2	0.0	1.0	0.8	
EC5	1.3	0.3	-0.92	0.6	-0.5	0.0	0.3	-0.2	0.3	0.9	N/A	-0.8	1.8	0.9	1.0	0.7	N/A	N/A	1.0	0.2	0.1	0.8	1.2	0.8	
EC6	-0.5	-1.1	-0.49	0.9	0.8	0.7	0.4	-0.1	0.4	0.8	N/A	-1.8	1.5	-1.2	1.4	0.4	N/A	N/A	0.4	-0.7	0.3	0.7	1.3	0.3	
EC7	0.1	-0.5	-0.33	0.9	1.0	0.5	0.3	0.1	0.6	0.9	N/A	1.8	1.4	-0.7	1.6	0.7	N/A	N/A	0.5	-0.3	0.4	0.8	0.8	1.1	
EC8	1.7	2.0	0.67	0.1	0.4	-0.9	1.4	0.9	2.2	2.6	N/A	2.7	0.8	-1.6	0.2	0.7	N/A	N/A	1.3	0.8	0.9	1.2	0.8	0.8	
EC9	0.9	0.3	-0.56	0.0	0.5	0.0	0.3	0.1	0.9	0.5	N/A	-1.2	0.8	0.6	0.6	0.6	N/A	N/A	0.7	0.3	0.1	0.3	0.0	0.4	

N/A – There were no projects with results to be classified as The Rest

Ratings shown have a difference above 1.

Source: Elaborated by the Author

APPENDIX H. Pearson correlation for Market-based knowledge source

Variables	Patent	Publication	Budget	Schedule	Technical quality	Overall	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	PM1	PM2	PM3	PM4	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9
Patent	1																																	
Publications	0.61***	1																																
Budget	-0.23	-0.18	1																															
Schedule	-0.02	-0.04	0.4*	1																														
Technical quality	-0.25	-0.32	0.41*	0.1	1																													
Overall	-0.53*	-0.61**	0.3	-0.32	0.88***	1																												
CP1	0.17	0.07	0.3	0.38	0.1	-0.19	1																											
CP2	-0.11	0.02	0.45*	0.71***	0.23	-0.13	0.62***	1																										
CP3	-0.28	-0.12	0.09	0.59**	0.04	0.21	0.46**	1																										
CP4	0.2	-0.06	0.13	0.49**	0.28	0.15	0.69***	0.48**	0.54**																									
CP5	-0.3	-0.33	0.34	0.76***	0.15	0.39*	0.56**	0.57**		0.52**	1																							
CP6	-0.2	-0.13	0.13	0.61***	0.13	0.08	0.48**	0.65***	0.58***	0.63***	0.81***	1																						
CP7	-0.08	-0.18	0.46**	0.6***	0.43*	0.24	0.52**	0.61***	0.49**	0.74***	0.74***	0.72***	1																					
CP8		0.15	0.51**	0.21	0.24	0.51**	0.56**	0.76***	0.87***	0.56**	0.76***	0.68***	1																					
MAPP1	-0.08	-0.18	0.19	0.47**	0.18	0.08	0.61***	0.56**	0.58***	0.72***	0.77***	0.81***	0.75***	0.69***	1																			
MAPP2	-0.07	-0.15	0.27	0.42*	0.36	0.35	0.65***	0.55**	0.51**	0.78***	0.61***	0.77***	0.77***	0.78***	0.68***	1																		
MAPP3	-0.09	-0.19	0.19	0.53**	0.2		0.58***	0.57**	0.49**	0.64***	0.74***	0.84***	0.66***	0.62***	0.84***	0.78***	1																	
MAPP4	-0.22		0.19	0.68***	0.16		0.43*	0.67***	0.62***	0.56**	0.77***	0.94***	0.72***	0.71***	0.76***	0.66***	0.73***	0.69***	1															
MAPP5	-0.1	-0.11	0.43*	0.67***	0.35	0.08	0.46**	0.68***	0.57**	0.58***	0.71***	0.67***	0.88***	0.61***	0.63***	0.73***	0.67***	0.69***	1															
MAPP6	0.39*	0.15	0.28	0.58***	0.26	-0.29	0.48**	0.62***	0.29	0.58***	0.38	0.45*	0.58***	0.48**	0.45*	0.55**	0.55**	0.41*	0.61***	1														
MAPP7	-0.02	-0.28	0.16	0.64***	0.04	-0.16	0.5**	0.61***	0.69***	0.66***	0.74***	0.73***	0.67***	0.68***	0.77***	0.56**	0.65***	0.72***	0.66***	0.43*	1													
PM1	-0.25	-0.2	0.22	0.63***	0.15	0.15	0.25	0.55**	0.85***	0.59***	0.69***	0.64***	0.73***	0.73***	0.64***	0.56**	0.5**	0.68***	0.8***	0.32	0.74***	1												
PM2	-0.01	-0.03	0.05	0.54**	0.17	0.13	0.34	0.44*	0.73***	0.69***	0.68***	0.83***	0.73***	0.84***	0.74***	0.7***	0.65***	0.85***	0.73***	0.41*	0.78***	0.8***	1											
PM3	0.26	0.18	0.13	0.38	0.04	0.07	0.39*	0.31	0.49**	0.65***	0.44*	0.64***	0.62***	0.76***	0.64***	0.62***	0.61***	0.62***	0.63***	0.42*	0.56**	0.6***	0.83***	1										
PM4	0.2	-0.2	0.24	0.4*	0.22	0.08	0.46*	0.4*	0.44*	0.74***	0.62***	0.66***	0.77***	0.68***	0.74***	0.7***	0.71***	0.52**	0.69***	0.61***	0.73***	0.56**	0.72***	0.74***	1									
EC1	-0.13	0.09	0.25	0.55**	0.17	-0.18	0.28	0.48**	0.77***	0.41*	0.62***	0.63***	0.52**	0.6***	0.54**	0.55**	0.57**	0.72***	0.62***	0.49**	0.61***	0.58***	0.72***	0.47**	0.45*	1								
EC2	-0.11	-0.14	0.32	0.59***	0.22	0.08	0.51**	0.58***	0.77***	0.76***	0.66***	0.71***	0.75***	0.85***	0.64***	0.72***	0.54**	0.72***	0.72***	0.46**	0.8***	0.8***	0.82***	0.61***	0.71***	0.7***	1							
EC3	-0.03	-0.07	0.25	0.71***	0.25		0.43*	0.67***	0.7***	0.67***	0.59***	0.68***	0.7***	0.75***	0.59***	0.68***	0.6***	0.7***	0.77***	0.78***	0.64***	0.72***	0.74***	0.59***	0.59***	0.7***	0.76***	1						
EC4	-0.08	-0.1	0.15	0.24	-0.12	-0.19	0.54**	0.22	0.53**	0.53**	0.42*	0.38	0.37	0.5**	0.67***	0.27	0.46*	0.4*	0.28	0.09	0.6***	0.44*	0.46**	0.49**	0.46**	0.38	0.56**	0.31	1					
EC5	0.45*	0.09	-0.07	0.25	0.02	-0.32	0.24	0.18	0.22	0.38	0.19	0.27	0.24	0.33	0.35	0.33	0.53**	0.17	0.31	0.73***	0.32	0.08	0.33	0.46**	0.55**	0.42*	0.17	0.51**	0.17	1				
EC6	-0.12	-0.18	0.15	0.53**	0.14	-0.07	0.14	0.34	0.79***	0.61***	0.55**	0.46**	0.6***	0.64***	0.54**	0.41*	0.39*	0.49**	0.5**	0.51**	0.59***	0.71***	0.6***	0.34	0.52**	0.64***	0.71***	0.73***	0.46**	0.33	1			
EC7	0.29	-0.03	0.05	0.51**	0.31	-0.18	0.47**	0.38	0.27	0.62***	0.54**	0.44*	0.65***	0.34	0.66***	0.44*	0.58**	0.47**	0.54**	0.62***	0.58***	0.38	0.49**	0.32	0.53**	0.44*	0.37	0.49**	0.3	0.49**	0.5**	1		
EC8	0.39*	0.45*	0.24	0.07	-0.08	-0.4	0.4*	0.03	-0.04	0.32	-0.1	-0.01	0.09	0.19	0.07	0.14	0.14		-0.07	0.4*	-0.09	-0.25	-0.05	0.17	0.12	0.21	0.1	0.14	0.33	0.41*	0.21	0.18	1	
EC9	0.33	0.19	0.05	0.14	0.04	0.28	0.12	0.41*	0.45*	0.15	0.35	0.26	0.55**	0.28	0.46**	0.21	0.37	0.29	0.45*	0.33	0.63***	0.59***	0.49**	0.51**	0.65***	0.41*	0.3	0.19	0.27	0.12	0.1	1		

* Correlation is significant at the p < 0.10 level; ** Correlation is significant at the 0.05 < p < 0.1 level; *** Correlation is Significant at the level p < 0.01.

APPENDIX I. Pearson correlation for whole sample – All sources

Variables	Patent	Publications	Budget	Schedule	Technical quality	Overall	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	PM1	PM2	PM3	PM4	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9
Patent	1***																																	
Publications	0.39***	1																																
Budget	-0.09	0.12	1																															
Schedule	0.18	0.01	0.41***	1																														
Technical quality	0.02	0.01	0.31**	0.33**	1																													
Overall	-0.02	0.14	0.29*	0.16	0.59***	1																												
CP1	0.03	-0.07	0.23	0.4***	0.4***	0.21	1																											
CP2	-0.12	-0.12	0.36***	0.55***	0.34**	0.08	0.71***	1																										
CP3	-0.15	-0.04	0.24*	0.31**	0.18	0.13	0.36***	0.6***	1																									
CP4	-0.05	0.01	0.19	0.32**	0.42***	0.24	0.63***	0.45***	0.53***	1																								
CP5	-0.12	-0.03	0.25*	0.45***	0.33**	0.2	0.53***	0.49***	0.52***	0.66***	1																							
CP6	-0.09	-0.09	0.21	0.19	0.16	0.05	0.44***	0.55***	0.6***	0.56***	0.67***	1																						
CP7	-0.18	0.05	0.33**	0.3**	0.36***	0.18	0.51***	0.55***	0.48***	0.7***	0.57***	0.66***	1																					
CP8	-0.02	0.12	0.27*	0.38***	0.28**	0.33**	0.48***	0.5***	0.66***	0.71***	0.57***	0.6***	0.6***	1																				
MAPP1	-0.18	-0.16	0.25*	0.33**	0.33**	0.13	0.64***	0.68***	0.62***	0.7***	0.67***	0.62***	0.6***	0.54***	1																			
MAPP2	-0.13	-0.03	0.24*	0.32**	0.44***	0.34**	0.59***	0.56***	0.55***	0.85***	0.68***	0.65***	0.73***	0.66***	0.69***	1																		
MAPP3	-0.12	-0.04	0.21	0.35**	0.31**	0.16	0.61***	0.57***	0.51***	0.73***	0.85***	0.76***	0.65***	0.61***	0.74***	0.79***	1																	
MAPP4	-0.05	-0.1	0.23	0.31**	0.22	0.07	0.44***	0.52***	0.6***	0.57***	0.77***	0.92***	0.57***	0.6***	0.6***	0.61***	0.75***	1																
MAPP5	-0.06	0.18	0.3**	0.33**	0.33**	0.16	0.46***	0.59***	0.52***	0.62***	0.6***	0.65***	0.88***	0.62***	0.57***	0.73***	0.66***	0.58***	1															
MAPP6	0.18	-0.01	0.16	0.48***	0.47***	0.1	0.66***	0.6***	0.31**	0.58***	0.55***	0.49***	0.54***	0.47***	0.53***	0.58***	0.61***	0.53***	0.57***	1														
MAPP7	-0.14	0.12	0.24*	0.12	0.13	0.2	0.4***	0.54***	0.56***	0.47***	0.42***	0.61***	0.69***	0.61***	0.52***	0.53***	0.49***	0.47***	0.68***	0.34**	1													
PM1	-0.17	-0.01	0.28**	0.34**	0.26*	0.11	0.43***	0.5***	0.51***	0.54***	0.44***	0.5***	0.73***	0.5***	0.54***	0.51***	0.43***	0.4***	0.63***	0.34**	0.56***	1												
PM2	-0.01	-0.14	0.07	0.2	0.21	0.14	0.44***	0.29**	0.35**	0.54***	0.49***	0.5***	0.46***	0.53***	0.52***	0.5***	0.52***	0.51***	0.46***	0.43***	0.24*	0.49***	1											
PM3	-0.02	0.01	0.09	0.19	0.23*	0.12	0.4***	0.39***	0.46***	0.63***	0.54***	0.66***	0.65***	0.6***	0.56***	0.65***	0.67***	0.65***	0.62***	0.52***	0.48***	0.41***	0.62***	1										
PM4	0.03	-0.24*	0.22	0.26*	0.17	0.17	0.35***	0.34**	0.39***	0.43***	0.33**	0.48***	0.47***	0.56***	0.44***	0.47***	0.44***	0.42***	0.43***	0.39***	0.37***	0.34**	0.69***	0.57***	1									
EC1	0.11	-0.07		0.38***	0.08	0.21	0.1	0.19	0.32**	0.23*	0.27**	0.23	0.12	0.29**	0.22	0.35***	0.31**	0.22	0.22	0.15	0.07	0.08	0.39***	0.18	0.44***	1								
EC2	-0.11	-0.11	0.23*	0.5***	0.4***	0.25	0.55***	0.58***	0.52***	0.66***	0.48***	0.49***	0.6***	0.66***	0.68***	0.53***	0.46***	0.62***	0.59***	0.48***	0.53***	0.55***	0.59***	0.47***	0.4***	1								
EC3	0.07	0.03	0.18	0.24*	0.26*	0.02	0.39***	0.38***	0.57***	0.42***	0.43***	0.53***	0.42***	0.64***	0.45***	0.44***	0.41***	0.51***	0.51***	0.5***	0.49***	0.3**	0.46***	0.43***	0.48***	0.29**	0.46***	1						
EC4	-0.24*	-0.11	0.14	0.06	0.06	0.08	0.41***	0.42***	0.6***	0.48***	0.32**	0.43***	0.44***	0.46***	0.62***	0.42***	0.4***	0.35***	0.4***	0.17	0.6***	0.38***	0.31**	0.46***	0.31**	0.23*	0.57***	0.34**	1					
EC5	0.32**	0.15	0.06	0.33**	0.3**	0.07	0.29**	0.27**	0.32**	0.36***	0.28**	0.32**	0.21	0.36***	0.35***	0.38***	0.42***	0.29**	0.31**	0.62***	0.26*	0.08	0.25*	0.41***	0.35***	0.27*	0.4***	0.52***	0.25*	1				
EC6	0.08	-0.03	0.12	0.39***	0.27*	0.07	0.23*	0.32**	0.41***	0.46***	0.36***	0.56***	0.55***	0.42***	0.35***	0.44***	0.36***	0.49***	0.5***	0.46***	0.35**	0.53***	0.38***	0.48***	0.49***	0.38***	0.52***	0.36***	0.26*	0.36***	1			
EC7	0.19	-0.02	0.17	0.4***	0.33**	0.11	0.43***	0.35**	0.34**	0.42***	0.59***	0.55***	0.35**	0.32**	0.47***	0.41***	0.55***	0.63***	0.34**	0.55***	0.2	0.19	0.32**	0.36***	0.39***	0.27*	0.29**	0.43***	0.12	0.46***	0.47***	1		
EC8	0.36***	0.22	0.11	0.24*	0.06	0.13	0.24*	0.24*	0.16	0.17	0.13	0.21	0.12	0.17	0.17	0.22	0.23*	0.16	0.13	0.25*	0.18	-0.12	-0.1	0.16	0.2	0.49***	0.13	0.24*	0.21	0.34**	0.34**	0.34**	1	
EC9	0.19	0.18	0.19	0.2	0.28**	0.16	0.34**	0.22	0.45***	0.39***	0.16	0.26*	0.38***	0.5***	0.28**	0.4***	0.17	0.22	0.35***	0.44***	0.4***	0.32**	0.38***	0.44***	0.46***	0.16	0.5***	0.56***	0.25*	0.37***	0.31**	0.23	0.13	1

* Correlation is significant at the $p < 0.10$ level; ** Correlation is significant at the $0.05 < p < 0.1$ level; *** Correlation is Significant at the level $p < 0.01$.

APPENDIX J. Pearson correlation for Both-based sample

Variables	Patent	Publications	Budget	Schedule	Technical quality	Overall	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	PM1	PM2	PM3	PM4	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9
Patent	1																																	
Publications	0,27	1																																
Budget	0,29	-0,01	1																															
Schedule	0,31	0,08	0,88***	1																														
Technical quality	0,29	0,24	0,33	0,54**	1																													
Overall	0,39	-0,23	0,3	0,4	0,39	1																												
CP1	-0,1	-0,42	0,37	0,44	0,25	0,26	1																											
CP2	-0,05	-0,25	0,47*	0,59**	0,35	0,05	0,81***	1																										
CP3	0,38	0,05	0,25	0,37	0,41	-0,14	0,17	0,41	1																									
CP4	-0,03	0,04	0,1	0,07	0,23	-0,24	0,4	0,21	0,5*	1																								
CP5	0,02	0,06	0,04	0,09	0,06	-0,37	0,39	0,46	0,54**	0,69***	1																							
CP6	0,3	-0,31	0,16	-0,02	0,06	-0,06	0,35	0,32	0,51*	0,44	0,65**	1																						
CP7	-0,43	-0,06	0,21	0,11	0,14	-0,43	0,41	0,37	0,15	0,63**	0,56**	0,41	1																					
CP8	0,3	0,34	0,61**	0,54*	0,13	0,22	0,34	0,35	0,43	0,57**	0,3	0,3	1																					
MAPP1	-0,01	-0,22	0,24	0,11	0,09	-0,43	0,51*	0,51*	0,45	0,43	0,67***	0,77***	0,63**	0,18	1																			
MAPP2	0,1	0,02	0,01	0,17	0,52*	-0,09	0,46	0,48*	0,68***	0,81***	0,77***	0,52*	0,47*	0,34	0,47*	1																		
MAPP3	-0,12	-0,06	0,01	-0,01	-0,02	-0,39	0,53*	0,45	0,45	0,79***	0,94***	0,67***	0,63**	0,45	0,75***	0,74***	1																	
MAPP4	0,35	-0,2	0,24	0,1	0,06	-0,05	0,32	0,34	0,53*	0,48*	0,74***	0,96***	0,45	0,51*	0,7***	0,55**	0,7***	1																
MAPP5	0,12	0,37	0,21	0,18	0,14	-0,52	0,31	0,46	0,26	0,44	0,69***	0,41	0,61**	0,57**	0,63**	0,47*	0,63**	0,52*	1															
MAPP6	0,18	-0,21	0,38	0,36	0,21	0,41	0,64**	0,65**	0,2	0,1	0,37	0,58**	0,35	0,42	0,4	0,28	0,37	0,61**	0,35	1														
MAPP7	-0,24				0,18	0,16	0,26	0,32	0,33	0,57**	0,36	0,46	0,48*	0,14	0,48*	0,5*	0,46	0,34	0,5*	1														
PM1	-0,29	-0,28	0,68***	0,54*	0,21	0,02	0,49*	0,36	0,23	0,49*	0,13	0,24	0,7***	0,28	0,48*	0,16	0,3	0,22	0,13	0,28	1													
PM2	0,16	-0,08	0,19	-0,05	0,02	-0,26	0,38	0,24	0,17	0,19	0,32	0,68**	0,43	-0,03	0,82***	0,12	0,46	0,55*	0,43	0,56**	-0,09	0,37	1											
PM3	-0,06	0,11	-0,08	-0,18	0,32	-0,3	0,12	0,03	0,19	0,46*	0,58**	0,61**	0,62**	0,06	0,62**	0,53*	0,6**	0,56**	0,44	0,2	0,49*	0,25	0,61**	1										
PM4	0,38	-0,33	0,4	0,37	0,41	0,16	0,52*	0,49*	0,59**	0,27	0,43	0,8***	0,26	0,23	0,74***	0,44	0,45	0,73***	0,26	0,58**	0,1	0,45	0,67**	0,43	1									
EC1	0,4			0,16	0,3	0,07	0,25	0,31	0,74***	0,3	0,25	0,28	-0,32	0,01	0,24	0,47*	0,28	0,18	-0,06	0,07	-0,22	-0,06	0,12	-0,05	0,45	1								
EC2	0,18	0,07	0,52*	0,49*	0,53**	0,43	0,45	0,32	-0,04	-0,08	-0,19	0,09	0,04	0,13	0,22	-0,07	-0,07	0,04	0,43	0,44	0,43	0,14	0,5*	0,15	1									
EC3	0,67***	0,27	0,35	0,32	0,41	0,06	0,06	0,29	0,56**	0,02	0,39	0,63**	0,08	0,33	0,5*	0,31	0,25	0,65**	0,44	0,51*	0,1	0,59**	0,44	0,66***	0,35	0,31	1							
EC4	-0,18	-0,07	0,06	-0,1	0,4	-0,39	0,02	0,21	0,31	0,28	0,19	0,38	0,26	0,01	0,35	0,39	0,24	0,26	0,11	0,07	0,4	0,17	0,21	0,51*	0,31	0,22	0,23	0,24	1					
EC5	0,58**	0,16	0,41	0,45	0,68***	0,55*	-0,01	0,22	0,36	-0,28	-0,13	0,25	-0,23	0,17	0,02	0,08	-0,26	0,23	-0,05	0,43	0,08	0,17	0,12	0,52*	0,31	0,58**	0,73***	0,35	1					
EC6	0,24	-0,33	0,34	0,26	0,36	-0,04	0,33	0,35	0,65**	0,39	0,46*	0,81***	0,46*	0,1	0,79***	0,49*	0,47*	0,74***	0,27	0,4	0,06	0,52*	0,68**	0,59**	0,89***	0,33	0,23	0,64**	0,39	0,39	1			
EC7	0,48*	-0,32	0,28	0,25	0,32	0,23	0,55**	0,56**	0,54*	0,19	0,47	0,82***	0,19	0,1	0,66**	0,48*	0,46	0,75***	0,29	0,7***	0,12	0,17	0,74***	0,39	0,85***	0,52*	0,3	0,76***	0,23	0,53*	0,82***	1		
EC8	0,35	-0,16	-0,03	0,05	0,21	0,38	0,52*	0,61**	0,28	0,58**	0,58**	-0,1	0,05	0,48	0,69***	0,55*	0,49*	0,19	0,33	0,23	-0,2	0,32	0,37	0,51*	0,79***	0,01	0,52*	0,42	0,28	0,44	0,8***	1		
EC9	0,24	0,13	0,29	0,47*	0,71***	0,47	0,09	0,16	0,41	-0,09	-0,23		-0,14		0,12	-0,25	-0,07	-0,23	0,25	-0,2	0,34	0,14	0,08	0,41	0,34	0,53*	0,42	0,13	0,7***	0,41	0,35	0,05	1	

* Correlation is significant at the $p < 0.10$ level; ** Correlation is significant at the $0.05 < p < 0.1$ level; *** Correlation is Significant at the level $p < 0.01$.

APPENDIX K - Pearson correlation for Science-based sample

Variables	Patent	Publications	Budget	Schedule	Technical quality	Overall	CP1	CP2	CP3	CP4	CP5	CP6	CP7	CP8	MAPP1	MAPP2	MAPP3	MAPP4	MAPP5	MAPP6	MAPP7	PM1	PM2	PM3	PM4	EC1	EC2	EC3	EC4	EC5	EC6	EC7	EC8	EC9
Patent	1																																	
Publications	0.32	1																																
Budget	-0.21	0.45**	1																															
Schedule	0.23		0.13	1																														
Technical quality	0.17	0.17		0.56***	1																													
Overall	0.06	0.56**	0.56**	0.5**	0.36	1																												
CP1	0.01	0.01	0.14	0.39*	0.79***	0.29	1																											
CP2	-0.18	-0.13	0.21	0.4*	0.48**	0.28	0.72***	1																										
CP3	-0.29	-0.03	0.4*	0.17	0.3	0.29	0.53**	0.76***	1																									
CP4	-0.25	0.02	0.27	0.29	0.65***	0.38*	0.69***	0.52**	0.56**	1																								
CP5	-0.08	0.11	0.21	0.38*	0.62***	0.51**	0.68***	0.43*	0.5**	0.77***	1																							
CP6	-0.3	0.13	0.23		0.28	0.19	0.51**	0.63***	0.7***	0.6***	0.61***	1																						
CP7	-0.12	0.25	0.4*	0.23	0.43*	0.31	0.55**	0.63***	0.59***	0.74***	0.51**	0.83***	1																					
CP8	-0.19	0.18	0.37	0.2	0.49**	0.5**	0.61***	0.57***	0.74***	0.68***	0.66***	0.74***	0.69***	1																				
MAPP1	-0.29	-0.13	0.28	0.32	0.53**	0.35	0.71***	0.8***	0.69***	0.78***	0.62***	0.51**	0.55**	0.56***	1																			
MAPP2	-0.32	0.02	0.3	0.29	0.54**	0.38*	0.6***	0.6***	0.56**	0.95***	0.71***	0.7***	0.84***	0.68***	0.78***	1																		
MAPP3	-0.16	0.1	0.2	0.36	0.55**	0.45**	0.7***	0.61***	0.56***	0.8***	0.91***	0.76***	0.72***	0.75***	0.69***	0.85***	1																	
MAPP4	-0.27	-0.01	0.16	0.22	0.45**	0.34	0.61***	0.59***	0.75***	0.73***	0.85***	0.87***	0.67***	0.78***	0.58***	0.73***	0.87***	1																
MAPP5	-0.12	0.25	0.31	0.17	0.4*	0.35	0.53**	0.61***	0.57***	0.74***	0.52**	0.85***	0.98***	0.71***	0.55**	0.84***	0.72***	0.69***	0.64***	1														
MAPP6	0.06	-0.06	-0.03	0.48**	0.72***	0.2	0.79***	0.57***	0.37	0.75***	0.71***	0.51**	0.63***	0.58***	0.59***	0.7***	0.72***	0.65***	0.64***	0.29	1													
MAPP7	-0.17	0.33	0.48**	-0.11	0.22	0.31	0.4*	0.63***	0.67***	0.44*	0.26	0.77***	0.77***	0.69***	0.52**	0.56**	0.48**	0.48**	0.8***	0.07	0.33	1												
PM1	-0.05	0.21	0.38	0.11	0.45**	0.13	0.55**	0.58***	0.39*	0.56***	0.42*	0.66***	0.73***	0.32	0.54**	0.6***	0.51**	0.47**	0.69***	0.44*	0.58***	0.07	0.33	1										
PM2	-0.07	-0.21	0.06	0.08	0.33	0.3	0.53**	0.21	0.17	0.54**	0.45**	0.26	0.32	0.45**	0.36	0.47**	0.47**	0.37	0.3	0.45**	0.07	0.33	0.07	0.33	1									
PM3	-0.2	-0.13	0.07	0.28	0.48**	0.28	0.59***	0.64***	0.6***	0.73***	0.59***	0.7***	0.75***	0.8***	0.53**	0.78***	0.75***	0.77***	0.76***	0.76***	0.5**	0.36	0.53**	1										
PM4	-0.16	-0.21	0.24	0.19	0.16	0.28	0.26	0.3	0.32	0.35	0.19	0.3	0.38	0.63***	0.28	0.39*	0.34	0.29	0.36	0.32	0.31	0.15	0.7***	0.61***	1									
EC1	0.09	-0.17	-0.15	0.42*	-0.03	0.42*	-0.06	-0.02	-0.09	0.1	0.1	-0.03	0.07	0.14	0.07	0.19	0.2	0.01	0.11	0.05	-0.07	-0.18	0.3	0.14	0.42*	1								
EC2	-0.26	-0.19	0.03	0.44*	0.59***	0.32	0.65***	0.69***	0.53**	0.82***	0.57***	0.57***	0.72***	0.64***	0.73***	0.87***	0.74***	0.64***	0.73***	0.74***	0.46**	0.39*	0.39*	0.82***	0.37	0.32	1							
EC3	-0.1	0.01	0.13	-0.11	0.3	0.04	0.49**	0.26	0.49**	0.4*	0.37	0.45**	0.34	0.66***	0.38	0.32	0.38*	0.42*	0.37	0.4*	0.53**	0.08	0.26	0.35	0.37	0.04	0.3	1						
EC4	-0.41*	-0.17	0.23	-0.03	0.23	0.21	0.45**	0.67***	0.74***	0.51**	0.31	0.61***	0.54**	0.56**	0.66***	0.59***	0.48**	0.53**	0.56**	0.25	0.67***	0.35	0.23	0.51**	0.23	0.15	0.67***	0.39*	1					
EC5	-0.01	0.12	-0.06	0.35	0.64***	0.14	0.58***	0.45**	0.52**	0.69***	0.62***	0.55**	0.55**	0.68***	0.55**	0.64***	0.68***	0.65***	0.56**	0.66***	0.38*	0.26	0.29	0.64***	0.31	0.2	0.65***	0.59***	0.37	1				
EC6	0.1	0.25	-0.03	0.37	0.42*	0.25	0.22	0.28	0.06	0.37	0.17	0.44*	0.62***	0.39*	0.11	0.45**	0.32	0.29	0.65***	0.48**	0.38	0.46**	0.15	0.53**	0.34	0.26	0.52**	-0.01	0.08	0.42*	1			
EC7	-0.08	0.28	0.19	0.45**	0.49**	0.38*	0.36	0.19	0.31	0.44*	0.76***	0.36	0.24	0.5**	0.32	0.4*	0.62***	0.62***	0.26	0.53**	0.07	0.09	0.04	0.36	0.08	-0.01	0.26	0.25	-0.05	0.54**	0.15	1		
EC8	0.34	0.28	0.11	0.54**	0.17	0.38	0.04	0.25	0.1	-0.03	0.09	0.13	0.23	0.23	0.14	0.1	0.2	0.01	0.25	0.13	0.33	0.01	-0.29	0.05	0.13	0.54**	0.2	0.2	0.05	0.32	0.39*	0.22	1	
EC9	0.08	0.18	0.37	0.16	0.48**	0.15	0.48**	0.35	0.49**	0.52**	0.33	0.4*	0.57***	0.66***	0.36	0.44*	0.33	0.39*	0.56***	0.63***	0.53**	0.28	0.27	0.55**	0.48**	-0.14	0.37	0.7***	0.21	0.55**	0.32	0.32	0.18	1

* Correlation is significant at the $p < 0.10$ level; ** Correlation is significant at the $0.05 < p < 0.1$ level; *** Correlation is Significant at the level $p < 0.01$.