PERFORMANCE EVALUATION OF PUBLIC AND PRIVATE R&D PARTNERSHIPS: A LEARNING AND KNOWLEDGE MANAGEMENT PERSPECTIVE

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Abstract

This paper focuses on organizational learning and knowledge management through the intersectoral research and development relationship between government, universities and private organizations and explores the conditions that influence its performance. A study of over 150 of these projects, funded by Spanish government agencies, is presented in this paper. We empirically investigate how participating firm characteristics, the locus of the R&D agreement, and its organizational characteristics influence intersectoral R&D project performance. Expected and unexpected results are presented and discussed. Performance is determined using a data envelopment analysis (DEA)-based model.

Keywords

R&D, partnerships, learning and knowledge management.

Introduction

In recent decades, there has been unprecedented growth in public-private research and development (R&D) cooperation in order to expand firms' knowledge bases and develop new skills. Many reasons exist for this cooperation, including competitive reasons, greater government support, industrial policy, and relaxed regulatory policies. Drucker (1995) suggested that the greatest change in the way business is being conducted is the accelerating growth of relationships based not on ownership, but on partnership. However, the success of this strategy in the long-term depends on the proper integration of knowledge and learning developed during the R&D process. What gives a firm a sustainable competitive advantage is not only the knowledge set that a firm possesses at one point in time, but also the capability to create, integrate and use such knowledge.

Over the last decade, the role of Public Research Centers (PRCs, a University and Public Research Organization) in fostering technical advances and innovation has intensified. The literature suggests that PRC and industrial firms have complementary resources and skills (eg. Bower, 1993; Betz, 1996; SRI International, 1997) thus allowing them to form natural partnerships. Public research is seen as a potential for accumulating knowledge and expertise that firms can draw upon for their own use. Santoro and Gopalakrishnan (2000) point out that while PRCs have access to intellectual resources and a world-class basic research infrastructure, industrial firms usually have practice expertise, financial resources, and employment opportunities for students. PRC collaborations provide opportunities for more applications-oriented research as well as helping to obtain better insights into curricula development and technological diffusion (Geisler & Rubenstein, 1989; Fassin, 1991; Bonaccorsi & Paccaluga, 1994). In addition, partner universities can obtain resources from private firms in order to finance their own research activities (Kennedy, 1986).Thus, the collaboration in R&D activities between firms and PRCs constitute a strategic element toward innovation in the productive sector and towards the achievement of better planning and exploitation of resources set aside for research in the public sector. In this sense, it is not surprising that the public/private relationship has been intensively implemented and studied in the last few years. Most of the empirical research has focused on two general issues: (1) the ways in which relationships between the two collectives has been materialized (Gibson and Johnston, 1974; Link and Rees, 1990; Bailetti and Callahan, 1992; Senker and Foulker, 1992; Bonacorsi and Picaluga, 1994; Faulker and Senker, 1994; Ham and Mowery, 1998), and (2) barriers that can make the establishment of relations between the two worlds difficult (Dean, 1981; Azároff, 1982; Fowler, 1984; Höglund and Persson, 1987; Van Dierdonk et al., 1990; Sheen, 1992; Lee, 1996). However, none of the literature has analyzed this relationship from the point of view of the process of creating and developing knowledge. We have observed that the gap in the literature and research available on these types of cooperative agreements, with a learning and knowledge management focus, is particularly evident. Knowledge management is a critical and central practice in research partnerships, yet managers and researchers still require additional explanatory models that they could use as guides in this environment.

To help bridge this gap, our paper, based on a learning and knowledge management perspective, presents a performance evaluation of public and private R&D partnerships. Firm characteristics, locus of the R&D agreement, and its organizational characteristics are all evaluated in terms of how well they perform. The research methodology utilizes a database of over 150 public-private R&D projects. The methodology applies data envelopment analysis (DEA) to determine the relative productivity ("efficiency") of the various projects. The relative productivity scores are then categorized, whereupon, non-parametric statistical testing is used to determine how well these characteristics differentiate poor performing projects from better performing ones.

Initially, before discussing the dimensions of the evaluation framework in detail, an overview of the cooperative learning process is presented. We view this background as important to the later dimensional discussions and evaluations. The data and methodology are both briefly discussed in the third major section. In the forth section, differences are analyzed by drawing on contextual (characteristics) data collected for the study. The concluding section discusses the main results and presents implications for the performance of Public and Private R&D Partnerships.

R&D cooperation, learning and knowledge management

A public/private R&D collaborative agreement means two or more partner organizations (firms and public research organizations) decide to coordinate their R&D activities through a cooperative project and to share the knowledge generated from this joint effort. Each partner brings their own expertise to the newly created project in the hope that this combination of skills will produce benefits for all those concerned. By bringing together organizations with different skills and knowledge bases, an R&D agreement creates unique learning opportunities for the learning partners (Inkpen, 1998). Larsson et al. (1998) described this interorganizational learning as distinct from organizational learning by including the learning synergy or interaction effect between the organizations that would not have occurred if there had not been any interaction.

The literature on knowledge management distinguishes two core processes in interorganizational learning: (1) the creation of new knowledge through interaction among organizations and (2) the transfer of the existing knowledge from one organization to another (Larsson et al. 1998). In this respect, the question confronting us now is how the individual partners must act to create this collective knowledge –the knowledge creating process- and how the collective knowledge can be transferred to their own organization –the knowledge transfer process.

The knowledge creating process

The target of a process for knowledge creation is to enhance the potential of creating innovations as part of an adaptive behavior to be able to respond to environmental demands (Von Krogh et al, 2001). Many researchers have come to the conclusion that solving problems creates knowledge (Jaikumar and Bohn (1986); Hayes et al. (1988) and Perez Lopez (1991)). This conclusion implies that a R&D agreement may recognize and define problems, generate and applied knowledge to solve problems, and further generate new knowledge through the action of problem solving (Nonaka, et al., 2000). By knowledge creation through problem solving, R&D partners refine project environment understanding, increase their absorptive capability, and improve their ability to react appropriately to future stimulus.

The creation of collective knowledge is not just an agglomeration of devices to gain access to an individual firms' knowledge. It should be more than a collection of individual experiences. Senge (1990) posits that for learning to take place at a group level, an alignment of the different individual learning processes is necessary in order to avoid wasted energy. From an organizational learning perspective, it requires a high degree of mutual involvement in problem recognition and problem solving processes. In the first step, partners must scan, notice and construct meaning about environmental changes. The recognition of the existence of a problem occurs when some stimuli indicates the need for new actions. This stimuli then leads to the second step, when partners jointly experience new work processes, tasks, technological characteristics etc., to solve a problem.

Von Krogh et al. (2001) propose an iterative and multistage process for knowledge creation that obligate partners to spend considerable time together, discuss, and reflect upon their experiences, observe how their colleagues solve tasks and interact with technologies, explain, and give sense to their own actions. R&D agreement's members must establish relationships via language and thought in order to coordinate their learning processes. Dialogue (Isaacs, 1993) has been identified as a key aspect of this integrating process[1]. Individual knowledge needs to be disclosed, shared and legitimized until it becomes part of the group knowledge. R&D cooperation knowledge is the result of the construction and interaction of numerous individual organization perspectives during problem recognition and problem solving processes.

The knowledge transfer process

The knowledge creating process that happens in the R&D agreement does not guarantee that firms benefit from such knowledge on a larger scale. At this point, the problem an organization faces is transferring that knowledge. For this transfer to take place, it is essential that the knowledge created through the cooperation agreement is introduced and materialized in the operational systems of the organization, improving its activities.

Although R&D cooperation is a means through which firms learn, the created knowledge needs to be communicated and integrated into its organizational routines in order to impact organizational effectiveness. An individual organization learns by changing its actual routines (Argyris and Shön, 1978). The intangible nature of knowledge assets prevents knowledge from being completely diffused and subsequently used in the organization, unless "mental models" are simultaneously transferred. If mental models are not shared by members changes in organizational routines and decision rules will not likely take place (Kim, 1993). Thus, the extents to which these mental models are shared determine their understanding of the problem, fostering its diffusion and facilitating its materialization.

Cohen and Levintal (1990) express this idea in terms of a capability called "absorptive capacity" which expresses the firm's ability to assimilate new knowledge and make use of the benefits of joint research. Absorptive capacity contributes to innovation because it tends to develop

[1] The dialogue has been called "the language of learning" (Nonaka and Takeuchi, 1995).

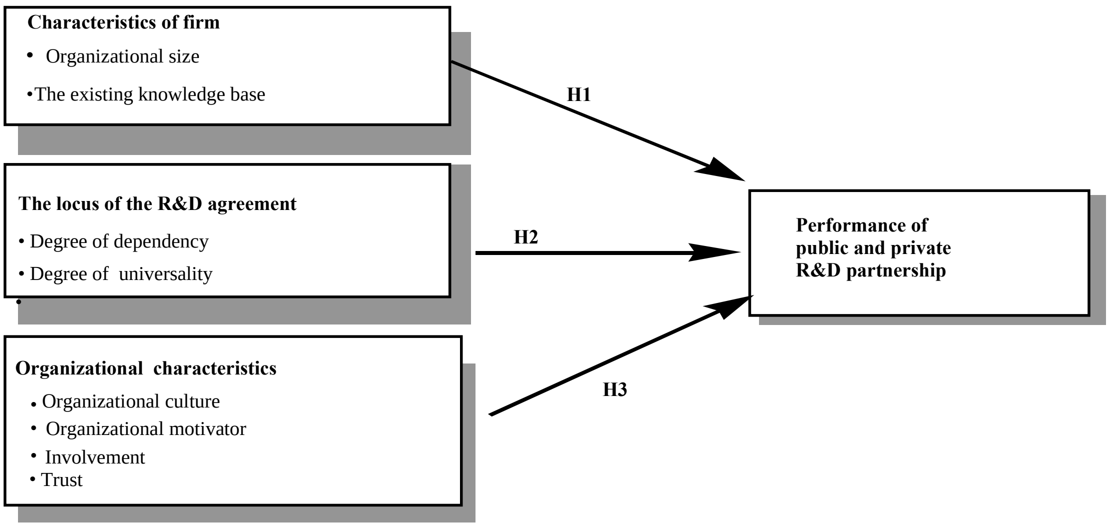
cumulatively and builds on prior related knowledge. Organizations with different practices have different assumptions, different outlooks, different interpretations of the world around them, and different ways of making sense of their encounters. Such differences challenge the fluidity of the agreement since emerging knowledge is hard to circulate (Brown and Duguid, 2001). Then organizations that possess relevant prior knowledge are likely to have a better understanding of the new knowledge, can generate new ideas, and develop new products. Organizations with a high level of absorptive capacity are likely to harness new knowledge from an R&D agreement to help their innovative activities. Without such capacity, they cannot learn or transfer knowledge from the R&D agreement.

To accelerate such processes, three conditions should be satisfied (Nahapiet and Ghoshal, 1998). First, the parties are aware of the opportunity to exchange the knowledge. Second, the parties involved expect the knowledge transfer to prove worthwhile for both parties. Third, the parties must be motivated to pursue the knowledge transfer.

Dimensions of knowledge management and learning processes for evaluation of R&D public/private relationships.

In this section we introduce some background on the three foundational dimensions that will be used in our evaluation: (1) characteristics of the firm, (2) locus of the R&D agreement, and (3) organizational characteristics of the R&D agreement. Figure 1 frames the relationships among these dimensions and the hypotheses sets (H1 to H3) that will be evaluated. Our analysis provides empirical results that highlight these three types of characteristics and their respective impact on R&D relationship performance.

Figure 1: A performance evaluation of public and private R&D partnership model.



Characteristics of the firm that collaborate with the PRC

Companies participating in R&D activities vary on a number of factors. These characteristics may be important in discriminating between good and poor R&D performers. For example, effectiveness at acquiring knowledge and know-how from the PRC is related to firm's capacity to learn (Hamel, 1991) which is linked to (1) the size of the organization, and (2) the existing knowledge base.

Organizational size

The size of an organization may provide insight into the learning model developed by a firm. Le Bas (1993) puts forward two learning models: complex learning, undertaken by the larger companies which have a research department, and simple learning, undertaken by less structured companies which gain access mainly to technology by purchase of equipment and technical assistance. Other differences in innovation and technology development used by smaller companies have been well established in the literature, ranging from resources available to partnership development requirements (Hoffman, et al., 1998). Rothwell and Dogson (1991) list the advantages possessed by large and small sized organizations to innovate[2].

The key argument for a firm to cooperate is that it will thereby acquire complex knowledge that it currently lacks. To be able to absorb such capabilities, it is necessary that the firm has its own knowledge base, which may only be obtained if it has previously carried out research activities (Cohen and Levinthal, 1989, 1990). This previous knowledge acquisition is more likely to be the case with large sized firms. The lack of an own knowledge base, more frequently in small companies, decreases the efficiency of a firm in assimilating new knowledge.

The existing knowledge base

The organizational learning perspective highlights the importance of knowledge accumulation and exploitation within organizations (Blackler, 1995; Daft and Weick, 1984). Given the strong cumulative nature of scientific knowledge, the firm's base of knowledge prior to the cooperation agreement influences the effective acquisition and utilization of new knowledge. As Powell et al. (1996) argue, knowledge facilitates the use of other knowledge. What can be learned is crucially affected by what is already known. Firms that possess superior capabilities to value and apply knowledge would, in essence, have superior innovation and performance. Thus, from this point of view, independent efforts in R&D will be positively related to performance of the R&D relationship (George et al. 2001).

Based on these initial observations and categories concerning the characteristics of the firm within the collaborative partnership the following set of hypotheses is developed:

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[2] Rothwell and Dogson (1991) pointed out that the large firms enjoy material advantages: financial resources and qualified staff and technological networks, commercial resources, etc. The small ones, can count on behavioural advantages: managerial dynamism, organizational flexibility, rapid internal communication, high degree of adaptability etc.).

HYPOTHESIS 1a: The R&D agreements will have better performance in terms of relative efficiency if they are formed with larger sized firms.
HYPOTHESIS 1b: The R&D agreements will have better performance in terms of relative efficiency if they are formed with firms that have an extensive existing knowledge base.

The locus of the R&D agreement

Underlying most R&D projects is the attempt to increase the knowledge base of an organization. Roussel et al. (1995) suggest that the only real product of R&D is knowledge. The R&D process is knowledge-intensive that not only uses existing knowledge, but also creates new knowledge, which provides competitive advantage to the firm. To investigate the firm's choice in terms of knowledge content and its relationship to other factors, we begin by defining the "locus of the R&D cooperation" which refers to the stage of technical development at which the R&D project operates.

Viewed broadly, innovation and technological change occurs in two extreme forms. In the first situation, the developing knowledge comes from the existing knowledge. In the second situation new knowledge is created with loose connections to existing knowledge. March (1991) expressed this idea of knowledge development and use in terms of exploration and exploitation. He argued that the essence of exploitation is the development firm's current competencies and the essence of exploration is experimentation with new alternatives. Exploitation involves less radical characterizations defined by such terms as refinement, choice, production, efficiency, implementation and execution. It uses conservative and routine processes that maintain stable relationships. In contrast, exploration includes more radical characterizations such as variation, risk taking, experimentation, flexibility, discovery and innovation (March, 1991). Likewise, exploration is characterized by the re-orientation of routines and processes and the search for new rules and goals instead of developing existing routines in a more efficient way.

Within this context, organizational learning has emphasized the importance the following dimensions of the R&D agreement: dependency, and universality of the associated knowledge.

Degree of dependency

This dimension expresses the dependency versus autonomy of the knowledge development process from other innovations or organizational processes. This aspect is related to classification that Henderson and Clark (1990) make between component and architectural knowledge. The fewer the functions or knowledge areas that are involved in the R&D project, the more autonomous it is. Thus, basic research can be implemented as an autonomous process. It is strongly knowledge led, demanding heavy investment in well equipped research laboratories and R&D is comparatively remote (less dependent) from both the user and production. On the other hand, applied research requires strong feedback between technological users, suppliers, and producers thus increasing the project organizational dependency between the diverse functional knowledge areas involved in the R&D project. In this respect Henderson and Cockburn (1994) and Pisano (1994) concluded that the ability to integrate different knowledge streams and competence is a critical successful factor.

According to their findings, innovation dependency is related to difficulties with communication to users. The more dependent the existing R&D project, the more difficult and costly it is to internalize the project (and thus knowledge) for the firm. Therefore, the performance of the R&D cooperative agreements will be influenced by the extent to which knowledge in the field is systemic or related to other innovations. It may determine the level of knowledge transfer and transference complexity, such as oral transmission, repeated observation of practice embodied by researchers or workers, or technical reports as channels for accessing knowledge and expertise.

Autonomous knowledge can exist independently whereas systemic knowledge cannot or should not be decomposed into independent parts. Because dependent (systemic) knowledge is typically held organization-wide it is collective in nature. Moreover, since it is difficult for any one person to understand the whole system, it is typically tacit. On the basis of these arguments we propose a positive relationship between the R&D cooperation agreement performance and the level of autonomy of the research activity.

The degree of universality

This concept is related to what other authors have referred to as universal versus localized knowledge (Bonaccorsi and Piccaluga, 1994). Using their description universality means the extent to which knowledge can be applied to various target problem domains, even different from the source domain. With respect to this factor, generic knowledge is highly universal as opposed to localized knowledge that can only be used within its source domain.
This R&D project characteristic has not received much attention in the literature although it may have a direct impact on the outcomes of the R&D relationship. Bonaccorsi & Piccaluga (1994) concluded that the degree of universality of knowledge generated within the R&D linkage has an impact on both the motivations to enter into the agreement and the institutional arrangement. Likewise, Yang, et al (1999) point out that how generic the knowledge is may affect the R&D agreement outcomes.

Localized knowledge is more easily appropriated than universal knowledge, even when universal knowledge can be more readily codified. Despite this fact a firm may have no other option than to look for scientific knowledge when local solutions to specific problems are ineffective or too costly to develop. Universal knowledge, especially intense in basic research projects and at the beginning of the development of the knowledge field, may eventually result in dramatic productivity increases and cost reduction in activity design (e.g. algorithms for parallel computing, new design tools, simulation techniques and so on). But, universal knowledge may be less useful than specific knowledge for the organization. Global time-based competition and reduced product life cycles do not allow firms to fully market and exploit basic research output, and thus make such research a risky undertaking. The more universal the knowledge the more it is capable of producing broad and indiscriminate benefits and providing impetus for future advances in knowledge. We can categorize universal knowledge as more characteristic of basic research while localized knowledge is frequently applied research oriented. Thus, the further along the local knowledge development is the more likely that the R&D project will be successful in the short term. It is expected that universal knowledge is more positively associated to outcomes and performance in the long term.

Based on these initial observations and categories concerning the nature of the R&D project the following hypotheses are developed:
HYPOTHESIS 2a: R&D agreements with R&D projects that are NOT part of a larger project will perform better in terms of relative efficiency.
HYPOTHESIS 2b: R&D agreements with R&D projects having local (versus universal) knowledge requirements will perform better in terms of relative efficiency, provided these efficiency scores use short term measures.

Organizational characteristics of the R&D agreement

Considering that the most important source of a firm's sustainable competitive advantage resides in its knowledge assets and its capacity to increase them, an adequate functioning of this learning process is paramount to the preservation of a firm's competitiveness. Knowledge and innovations are economically valuable, but, if mismanaged, they can quickly produce serious losses (Faerman, et al, 2001). Focusing on the process and activities occurring between industrial firms and PRCs is important because they ultimately are related to the level of outcomes, such us firm performance and sustained competitive advantage (Santoro and Gopalakrishnan, 2000). Industry-PRC research agreement includes a variety of organizational characteristics that determine the efficiency of the knowledge creating process and the knowledge transfer process. The characteristics used to analyze this relationship include: organizational culture, organizational motivator, involvement, and trust.

Organizational culture

Organizational culture is a complex construct consisting of many concepts including: values (Barney, 1986), basic assumptions (Schein, 1990) and shared meaning (Deal and Kennedy, 1982). Some organizations prefer stability and the status-quo rather than the uncertainty of change (Santoro and Gopalakrishnan, 2000). Culture, therefore, determines the kinds of knowledge sought and acquired along with the kinds of knowledge building activities that are tolerated and encouraged. Leonard-Barton, (1995) says that culture serves as a knowledge-screening and knowledge-control mechanism. Likewise, we associate culture to the reasons that take firms to develop a collaboration agreement with the PRC partner.

Culture is a determinant for the motivation leading private profit-oriented firms to enter into an R&D relation with a PRC. Economic analyses of technological innovation argue that the motivation to enter into an R&D relation with a PRC is to gain access to basic knowledge, especially when internal incentives to invest are low. However the motivation to initiate relationships with the PRC may be richer and more complex. These initial benefits and motivations may impact the eventual level of performance for the R&D project. Having access to scientific frontiers, reduced development cost by delegating selected phases of the development process to the PRC, and increasing of financial and human resources, could be some of the motivations for firms in forming relationships with PRCs (Roessner & Bean, 1994; Roessner, et al., 1998). Motivation may determine how well an R&D project performs.

Following this argument, we propose that R&D agreement involved more in new knowledge streams related to the latest technological development may mean a longer term benefit than cultures being committed to an agreed course of action or set of specific knowledge initiatives. For example, access to scientific knowledge is more related to longer-term success than becoming involved in an R&D project in order to get cost reduction. In this regard, it is useful to consider the idea of network of practice developed by Brown and Duguid (2001). They argue that when practice does not prepare the ground, knowledge is unlikely to flow. In effect, organizations that search for new knowledge may not have the practice associated to that knowledge. Work practice, then, seems critical to understand and acquire knowledge from the PRC. The need to share some practices to be able to share new knowledge reveals the challenge that R&D agreements involved in the latest technologies face.

Organizational motivator (catalyst)

We now consider the group that originates and supports the R&D project, the ‘organizational catalyst’. These organizational participants often play the role of internal entrepreneur. Leaders with strong reputations can legitimize certain ways to deal with a problem, and prod and persuade people to act in ways favoring or inhibiting cooperation (Gray, 1989). According to this important organizational champion characteristic, we point out that the relative efficiency (performance) of the linkage depends on the ability of this group or individual to overcome the political, technical or economic barriers and resistance that the agreement encounters. Thus, performance of the R&D project may rely on the catalyst within the organization that sought out this project. We propose that the more that organizational motivators understand the R&D project the better the R&D agreement performance. This concept is partially derived from the literature on diversification (Chandler, 1962; Porter, 1987). An R&D agreement can not be successfully managed unless the research is understood. The better the understanding of the R&D project by the organizational motivator the more trust that exists which facilitates the knowledge transfer, which in turn increases the likelihood of a successful agreement.

Involvement

The degree of each partner’s commitment in a collaborative agreement should have a significant impact on the allocation of resources (Mothe and Quelin, 2001). According to Parkhe (1993), the first involvement consideration contemplated is the total budget assigned to the R&D activity associated with the partnership. Higher budgets, it can be argued, represent higher levels of involvement. Additionally, two other resource aspects are thought important: the public funding for development and the PRC’s resource involvement. Certain authors even show that the degree of involvement can also depend on the firm's size (Sinha and Cusumano, 1991). For example, public funding is extremely significant because it enables small firms to overcome resource barriers to involvement with the PRC. Likewise, the PRC's resource involvement gives an idea about the relative weight of the PRC in the linkage.

These three resources are investigated here. Clearly, a distinction between non-knowledge-related involvement (technical equipment and financing) and knowledge-related involvement (e.g. personnel, skills and knowledge) can also be considered (Olk and Young, 1997). It seems likely that performance varies according to the degree of involvement in the R&D project conducted by the research agreement. Thus, we hypothesize that the greater the involvement is, the higher the performance.

Trust

When a new private-public partnership is created, the partners may have initial uncertainties about working together, particularly if they have no prior cooperative relationships. If the firm and the PRC have worked together in the past or have prior collaboration experience, they may have more trust, less time to "get used to each other", and other factors which provide an impetus for a more productive relationship. First-hand dealings with others partly shape these attitudes. We learn who we can or cannot trust from personal experiences (Faerman, et al, 2001).

Organizational learning literature has recognized the importance of trust in cooperative agreements (Yang et al, 1999; Faerman, et al, 2001). Trust is essential for a long term relationship, since it enables partners to develop confidence about the other partners' abilities and expected behavior (Das and Teng, 1998; Luhmann, 1988). It allows technical professionals to build a relationship, strengthen the exchange of technical information and nurture mutual respect. When a high level of trust exists, the firm is more confident about the kinds of knowledge available in the R&D agreement and the way this knowledge can be acquired and exploited (Santoro and Gopalakrishnan, 2000). Consequently and since initial dispositions toward cooperation are shaped by personal experiences (Faerman, et al, 2001), previous experiences in R&D cooperation may help partners to become more committed to making the R&D agreement succeed. Thus, following this argument, previous experience in R&D cooperation contributes to more openly shared and developed knowledge and, in turn, to better performance.

Based on these initial observations and categories concerning the nature of the R&D linkage the following hypotheses are developed:
HYPOTHESIS 3a: R&D agreements developed by stable (versus dynamic) cultures will perform better in terms of relative efficiency.
HYPOTHESIS 3b: R&D agreement originated by groups or individuals close to the project development will perform better in terms of relative efficiency
HYPOTHESIS 3c: R&D agreements with a large amount of resources dedicated to the project will perform better in terms of relative efficiency.
HYPOTHESIS 3d: R&D agreements where partners have had previous cooperative experience with each other will perform better in terms of relative efficiency.

Research Methodology

Sample Characteristics and Data collection

In this study we investigate a type of public-private R&D partnership, these partnerships are defined as *"concertados"* projects (CP). Additionally, the investigation is from the perspective of the privately-owned partner firm. The CP is an instrument of the Spanish Plan Nacional de I+D[3] (National Science Research and Technological Development Plan) directed to finance between 40% and 50% of the total cost of these projects through refundable incentives without interest. In order to be eligible for funding, these projects have to be pre-competitive research initiatives developed in the framework of a R&D alliance between companies and PRCs. Therefore, the company has to share the CP's cost with at least one PRC.

The analysis of these public and private R&D linkages is based on two data sources. The first one is an administrative database supplied by CDTI. The information provided is related to Spanish firms that participate in R&D Projects with at least one PRC. In addition, another questionnaire was designed to gather additional qualitative and perceptual information about these joint R&D projects. The questionnaire was used to acquire information related to the factors and contingencies defined in Figure 1.

The questionnaire was distributed among 317 firms that had applied for 496 CPs during the periods between 1988 until 1993. 118 companies responded to the questionnaire, which resulted in information on a total of 281 projects. After eliminating CPs with missing data a total of 159 projects were used in the final analysis, 32% of the project sample.

Performance factors and evaluation

Prior literature on performance evaluation in technology or research agreements provides a foundation for measures and factors used in this study. The most traditional approach of public and private R&D relationship performance evaluation is based on quantitative indicators. The number of technical problems solved, patents, inventions, and innovations, the presence of spin-off enterprises, the level of continuing industrial support are all examples of quantitative indicators (Geisler and Rubinstein, 1989). The advantage of this form of evaluation is that they are "hard" numbers that can be easily manipulated and analyzed. The disadvantage is the lack of intangible factor consideration.

Another issue is the distinction between long-term and short-term performance evaluation (Bonnacorsi and Piccaluga, 1994). Short-term indicators, usually the more concrete, estimate effects of the project on the firm's sales, employment, productivity and so on. The long-term performance of R&D relationships are typically more intangible, making them difficult to quantify. One such example is the "value" of learning produced by actual experience.

[3] The CP are administrated by the Centro de Desarrollo Tecnológico Industrial, (CDTI, Centre of Industrial Technological Development).

Geisler and Rubenstein (1989) point out that overall evaluation of benefits and successes can be applied using subjective opinion. This approach contemplates the possibility that university and industry, even different groups of people inside the firm, often have different views effecting what is viewed as a successful project. Bonnacorsi and Piccaluga (1994) hypothesize that the motivation of companies to enter into intersectoral R&D relationships influences their expectations regarding the achievement.

Maidique and Zirger (1985) define the level of success as the achievement of what was planned, desired or intended. It is assumed that performance depends on how well the intended goals are met, in technical or economic terms. Bonnacorsi and Piccaluga (1994) consider this notion very restrictive and not applicable to high uncertainty situations such as the creation of scientific and technological knowledge. In this situation, the “official” objectives are so unspecified that it is impossible to contrast their performance level. It is not a matter of assessing the adequacy of means to given goals, but of generating simultaneously, means and goals, indicating that the evaluation of performance of the R&D relationship may change from a purely instrumental role to a goal-generating role. Bozeman & Crow (1998), in their study of federal or federally funded laboratories, focused on the outputs from proprietary and public perspectives. Likewise, Georghiou and Roessner (2000) recommend a variety of measures, tools and techniques to observe and investigate the difficult to measure and multidimensional characteristics of intersectoral R&D relationships.

Thus, evaluating CP using varying measures and dimensions is recommended and appropriate. The DEA methodology helps bring together a number of performance dimensions, providing a relative performance evaluation of these projects. As will be described in more detail below, DEA uses multiple “input” and “output” factors in the evaluation. These multiple factors allow the evaluation of projects on multiple dimensions, simultaneously. The results of the DEA methodology are relative efficiency measures.

Performance Analysis Methodology and Data Envelopment Analysis

The methodological approach utilizes DEA for performance evaluation of the partnerships. DEA models are part of a class of multi-factor productivity models. DEA productivity models for a given “decision making unit” (DMU) use ratios based on the amount of outputs per given set of inputs. In this paper the DMU is a CP. The results of the DEA executions will be relative efficiency scores that measure the performance of the various CP. Unlike taking each performance measure separately and completing a regression on them (which is more of an averaging technique), DEA is an optimization approach that considers a number of factors simultaneously, providing a single performance measure for each data point (DMU)[4]. The major

[4] Charnes et al. (1993), argue that DEA is more effective for providing effective and ineffective performance, especially when multiple measures of performance and discretionary and/or exogenous variables are involved, as "the starting point for inducing theories about best-practice behavior" (pg. 9-10). Other arguments are also presented for the use of DEA over some other multivariate statistical techniques. The major argument is that a parametric functional form is not necessary using DEA and that central tendency approaches such as regression may hide characteristics of good performers.

difficulty with the DEA results is that they do not necessarily have some parametric characteristic for standard statistical inferencing purposes. The use of non-parametric statistical tests, as described in the next section, overcomes some of these limitations.

The general efficiency measure that is used by DEA can best be summarized by equation (1).

$$E_{ks} = \frac{\sum_{y} O_{sy} v_{ky}}{\sum_{x} I_{sx} u_{kx}} \tag{1}$$

where:

(E_{ks}) is the efficiency or productivity measure of CP *s*, using the weights of "test" CP *k*;

(O_{sy}) is the value of output *y* for CP *s*;

(I_{sx}) is the value for input *x* of CP *s*;

(v_{ky}) is the weight assigned to CP *k* for output *y*; and

(u_{kx}) is the weight assigned to CP *k* for input *x*.

In the basic DEA ratio model developed by Charnes, Cooper & Rhodes (CCR) (1978) the objective is to maximize the efficiency value of a test CP *k*, from among a reference set of CPs *s*, by selecting the optimal weights associated with the input and output measures. The maximum efficiencies are constrained to 1. The formulation is represented in expression (2).

maximize $$E_{kk} = \frac{\sum_{y} O_{ky} v_{ky}}{\sum_{x} I_{kx} u_{kx}}$$

subject to:

$$E_{ks} \leq 1 \qquad \forall \quad \text{CPs} \quad s \tag{2}$$

$$u_{kx}, v_{ky} \geq 0$$

This non-linear programming formulation (2) is equivalent to the following linear programming formulation (3) (see Charnes et al. (1978) for a complete transformation explanation):

maximize $$E_{kk} = \sum_y O_{ky} v_{ky}$$

subject to:

$$E_{ks} \leq 1 \quad \forall \quad \text{CPs } s$$

$$\sum_x I_{kx} u_{kx} = 1 \tag{3}$$

$$u_{kx}, v_{ky} \geq 0$$

The transformation is completed by constraining the efficiency ratio denominator in (2) to a value of 1. This is represented by the constraint $\sum_x I_{kx} u_{kx} = 1$.

The result of formulation (3) is an optimal "simple" or technical efficiency value (E_{kk}*) that is at most equal to 1. If E_{kk}* = 1, then it means that no other CP is more efficient (it lies on the optimal frontier) than CP *k* for its selected weights.

The dual of the CCR formulation (also defined as the "envelopment side") is represented by model (4):

minimize $$\theta$$

subject to:

$$\sum_s \lambda_s I_{sx} - \theta I_{sx} \leq 0 \qquad \forall \text{ Inputs } I$$

$$\sum_s \lambda_s O_{sy} - O_{ky} \geq 0 \qquad \forall \text{ Outputs } O \tag{4}$$

$$\lambda_s \geq 0 \qquad \forall \text{ CPs } s$$

The CCR model has an assumption of constant returns to scale for the inputs and outputs. To take into consideration the situation of variable returns to scale, a model introduced by Banker, Charnes & Cooper (1984) (BCC) is utilized. The BCC model has an additional convexity constraint defined by limiting the summation of the multiplier weights (λ) equal to one, or:

$$\sum_{s} \lambda_s = 1 \tag{5}$$

In this paper the DEA based performance model that is used in evaluating the performance of the partnerships is the one proposed by Rousseau & Semple (1995), which focuses on preservation of a unit's classification (e.g. what are the changes required to input and output values to maintain a unit's classification as efficient or inefficient). This approach is based on determining a unit's sensitivity to changes in the data values. The formulation used here to evaluate the CPs data set is the generalized Tchebycheff radius of classification preservation (GTR) model (6).

$$\text{minimize} \quad \alpha^{+} - \alpha^{-}$$

subject to:

$$\begin{aligned}
&\sum_{s \neq k} \lambda_s I_{sx} - \alpha^{+} I_{kx} + \alpha^{-} I_{kx} - I_{kx} \leq 0 \qquad \forall \ \text{Inputs } I \\
&\sum_{s \neq k} \lambda_s O_{sy} + \alpha^{+} O_{ky} - \alpha^{-} O_{ky} - O_{ky} \geq 0 \qquad \forall \ \text{Outputs } O \\
&\sum_{s \neq k} \lambda_s = 1 \\
&\lambda_s, \alpha^{+}, \alpha^{-} \geq 0
\end{aligned} \tag{6}$$

where α^{+} is the distance of an efficient unit from the Pareto frontier and α^{-} is the distance of an inefficient unit from the Pareto frontier. Unlike the other DEA models discussed above, the optimal value for this formulation can be either negative or positive. A positive value designates an efficient unit, while a negative value designates an inefficient unit. The magnitude of the objective value is also significant since it defines the robustness of the unit's score. The magnitudes of the objective values can serve as good measures to discriminate among units with similar classifications. It also allows an approach for good discrimination of efficient units (which are truncated at 1 for CCR and BCC DEA models). The GTR model has the BCC formulation as its underpinning and thus takes into consideration the varying returns to scale of DMUs.

Non-parametric Statistical Tests

The statistical testing will involve two non-parametric techniques to evaluate our hypotheses, the Mann-Whitney U-test evaluates the independence of two samples and the Kruskal-Wallis test evaluates the independence of multiple sample categorizations. These tests were executed on a PC version of SPSS.

The non-parametric tests are recommended for use on this data set because the efficiency score results do not necessarily fit within a standard normal distribution. The Mann-Whitney U-test has also been recommended for non-parametric analysis of DEA results by Brockett & Golany (1996) and Grosskopf & Valdmanis (1987).

Empirical results

The DEA-based performance evaluation model uses three input measures and three output measures. The inputs are the turnover of the company (total revenue), number of employees in the company, and total R&D budget. Three values were used as outputs, total number of patents from that project, total employment generated by the CP, and total income generated by the CP. The total number of patents output factor includes both national and international patents. The total employment generated includes laboratory employees, research and development employees, and total number of general employees. The impact on the Spanish economy, export technology produced by the CP that brought in revenues, and the technology transfer impacts of the new technology are all included. The data are mean normalized so that scale effects on the software package (the DEA programs are run on LINDO subroutines) would be minimized. The results are now presented.

We do need to emphasize that these outputs are what would be considered short-term measures. The pre-competitive character of the CP would have required the development of a measure of performance that represents not only the immediate or short-range results, but also to other possible long term impacts. Unlike in the efficiency domain, learning in the domain of R&D is a function of time and not only of short-term results (Levin, 2000). However, the distance existing between the research carried out and the improvements in products and process makes it difficult to capture a formalized assessment of long term outcomes of these partnerships. This is clearly a limitation of this study.

Major Findings

The evaluation of the results will be completed using Figure 1 as a guide.

Organizational size

Organizations were categorized into three sizes. For size determined by number of employees the following coding is used: 1 if the organizations had less than 50 employees, 2 if the organizations had between 51 and 500 employees, and 3 for larger organizations. The break-off points for small, medium and large organizations based on revenue is 1 if less than 500 Mpts (million pesetas), 2 if between 501-5000 Mpts, and 3 for larger revenue companies. The Kruskal-Wallis test was run for this data. Table 1 provides the results where the larger the ranking value the poorer the performance. We can see that the rankings were consistent with hypothesis 1a. They show, in both cases (significant at the .000 level), that larger organizations performed better than smaller organizations.

These results may be important to the PRC's in showing that there may be more synergy with larger organizations, thus providing better performance. Another issue that arises here is that the PRC needs to provide better guidance to smaller organizations in helping them perform better.

Table 1: Kruskal-Wallis Test Statistics for Size of Organizations

Size	Number (Revenue)	Mean Rank (Revenue)	Number (Employees)	Mean Rank (Employees)
Small (1)	43	214.72	69	209.06
Medium (2)	90	165.68	84	145.13
Large (3)	144	99.72	124	95.86
	Chi Square Value	83.03		89.22
	Significance	.000		.000

The existing knowledge base

A proxy measure of the ratio of R&D expenditures/Total Revenue is used to evaluate the existing knowledge base. To get the groupings we determined an average ratio. Thus, two groupings were made, projects that were above the average formed one group, and those that were below formed the other. This coding allowed for a 2-independent sample non-parametric test (the Mann-Whitney U-test) to evaluate a difference among organizations based on these categories. The results in Table 2 do not show support for hypothesis 1b since there was not a major statistical significance (significance = .167). Yet, the better performers seemed to be biased towards those organizations that had smaller than average ratios (mean ranks were 152 and 136 respectively for larger and smaller ratios). This organizational characteristic requires additional testing possibly introducing other (even qualitative) measures for knowledge existence.

Table 2. Test Statistics for the existing knowledge base

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
R&D/Revenue (K)	5601	.167

Degree of dependency

The amount of innovation dependency was determined by asking whether the project was part of a bigger project and whether it required more effort to get to actual production. As can be seen from the results (Table 3), there is a significant difference in performance between those CPs that were or were not a part of bigger projects. The finding in this case showed that those projects that were *not* part of a larger project or did *not* require additional effort to be produced ranked better. In both cases, there is an implication that these more focused and less complex projects (not part of bigger projects or no worry about additional steps for production) performed better. This supports hypothesis 2a and the intuition and findings of others (Gonard, 1998) who state that nature of the relationships existing around a project influence on the efficiency of the R&D relationship.

Table 3: Test Statistics for degree of dependency

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Part of Bigger Project	7043	.014
More effort needed to innovation being produced	7339	.004

Degree of universality. The spectrum of universality of knowledge used in this study includes: (1) knowledge does not exist; (2) knowledge exists theoretically; (3) practical experience with innovation at research level; (4) practical experience at industry level; and (5) knowledge has been applied by firm. As we can see from the results in Table 4, there seems to be no significantly different results in level of knowledge development when determining performance of the CPs. Thus, whether or not knowledge exists for the innovation being pursued in the project does not seem to matter in terms of eventual performance. Thus, hypothesis 3b is rejected.

Table 4: Test Statistics for degree of universality.

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Knowledge does not exist	2792	.226
Knowledge exists theoretically	9219	.577
Practical experience only at research level	5617	.649
Practical experience at industry level	8044	.721
Knowledge has been applied by firm	3232	.527

Organizational culture. Six categories of motivations leading firms to develop a CP are defined, including: 1. Access to expertise and knowledge; 2. Help in getting access to information on scientific developments; 3. Access to research infrastructure; 4. Cost reduction to the organization; 5. Access to public funding; and 6. Other. Those organizations that said yes for a category were coded with a “1”, no’s were coded with a “0”.

This category does not show any statistically significant discriminators on performance (Table 5). This lack of significance shows that hypothesis 3a is not supported. This finding supports a proposition that the content (the contribution of the PRC) of the R&D agreement does not seem as effective as the process (the way in which the agreement is developed) in determining ultimate performance of the CP.

Overall, there were some categories that were on the verge of significance. Access to research infrastructure (.116) and acquiring experience and knowledge (.149), seemed to be on the borderline. This bias in significance may show that knowledge is more important than the financial benefit of these relationships.

Table 5: Test Statistics for organizational culture.

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Access knowledge and experience	7195	.149
Scientific Tracking of Research Areas	8727	.361
Access to Research Infrastructure	7068	.116
Reduction of Costs to Organization	9071	.741
Access to Public Funding	8566	.455
Other	597	.105

Organizational motivators. This variable in this investigation focused on the type of motivator that supported the CP. To determine the motivator the respondents were asked: "The project idea comes from 'x'." The 'x' represents the project motivator. The responses were coded 1 for a "yes" and 0 for a "no". The motivator categories included: 1) business management, 2) R&D department, 3) operations department, 4) clients, 5) suppliers, 6) PRC (public research center), or 7) others.

The findings showed that those CP ideas that originated from business management seemed to perform more poorly than those that did not state that ideas originated from this group. The CP ideas that showed a statistically better performance were those that originated from R&D departments, consistent with hypothesis 3b, that the R&D agreement performance is related to the type of organizational catalyst within the firm. Yet, the rest of the motivator categories did not show a statistically significant difference (see Table 6), weakening the support for hypothesis 4b, but not outright rejecting it. This result may point to the fact that those closest to the project, who have direct control over the technical and operational outcomes and/or have the technical capabilities to select the more appropriate ideas, have more motivation to make sure the project is more successful. A result that may support the "Dilbert Principle" of engineers knowing better than management what will or will not work.

Table 6: Test Statistics for organizational motivator.

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Business Management	7102	.000
R&D Department	8274	.065
Operations Department	2381	.835
Clients	2243	.207
Suppliers	42	.230
Public Research Center (PRC)	1254	.745
Other	2092	.287

Involvement. The resources groupings are determined by calculating average budgets for company R&D programs, PRC budget and public funding budgets. Those projects with bigger than average budgets were coded as “1”, below average budgeted projects were coded “0”. This grouping was completed for each factor. The results were quite clear (Table 7), and consistent with the hypothesis 4c, showing that bigger budget projects perform better than smaller budget projects. This result may be supported by the possible synergy of larger projects and meeting thresholds for pursuing patents and potentially employing additional people, increasing involvement. There may be significant pressures on both sides of the project to perform for larger budget projects with high expectations driving performance. Smaller budget projects may not reach the necessary thresholds or the pressures to perform are lessened, thus allowing some of these projects to “slip through the cracks.” Some research has shown that poorly supported projects respond inadequately to changes in technical or budgetary plans (Ham & Mowery, 1998).

Table 7: Test Statistics for involvement

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Total Company Budget	3514	.000
PRC Budget	4843	.001
Public Funding	3915	.000

Trust. Previous experience (determined by asking if the firm worked with the PRC before), showed a significant result (Table 8) supporting hypothesis 3d. Those organizations that had previous experience with the PRC performed better than firms forming partnerships for the first time. This result was not surprising since learning occurs in the relationship allowing both sides to become more efficient in their dealings, and trust builds between the two entities. Another reason may be that previous partnership experiences were probably successful, thus later partnerships will build on that success. Geisler (1999) argues that unsuccessful relationships tend to be terminated, whereas successful agreements tend to be continued. Firms that did not have success initially would be less likely to partner with the same PRC.

Table 8: Test Statistics for trust.

Variable	Mann-Whitney U Test Statistic	Significance (2-tailed)
Did firm work with PRC previously	6293	.071

Summary and conclusion

Based on a learning and knowledge management perspective, we proposed an examination of the performance of public and private R&D relationships and the factors which may determine possible success (good performance) levels. We defined performance using multiple “input” and “output” variables and applied a DEA methodology to arrive at relative efficiency scores. The data set was based on intersectoral R&D relationships supported by Spanish companies and Public Research Centers. Performance conditions are analyzed from three perspectives:

characteristics of the firm, the locus of the R&D agreement and the organizational characteristics of the linkage. The empirical work was based on both qualitative and quantitative information.

Firm determinants

We observe that the firm's size influences performance. Larger organizations performed better than smaller organizations. This result shows the difficulties small organizations have in accessing PRC's expertise and resources. Their lack of financial support and limited resources seems to have impaired their capacity to develop new knowledge and implement the results of the R&D agreement. Given the relevance that the SMEs have in the Spanish productive sector, it is necessary to design instruments that permit the modernization of these companies. If not, it will impede small organizations in creating and developing a technological foundation.

Locus of the R&D agreement determinants

Our evidence emphasizes that, when the R&D project depends of other R&D projects or functions, performance is not as good. To avoid some of the problems of complexity and dependence, innovation should be integrated, especially with the production and commercialization process (Ingham and Mothe, 1998). The ability to integrate different knowledge streams and competence is critical successful factor.

Organizational R&D agreement determinants

Successful R&D public/private partnerships require a minimum (threshold) budget that allows them to respond to the dynamism and change associated with R&D projects. In order to be more efficient, our research suggests the need to concentrate on the development process of the R&D agreement. The lack of significance of building relationships goes against some of the research, especially when building relationships is based on trust. The notion that trust is critical in R&D partnerships has been discussed in the literature (Hamel, 1991; Dogson, 1993). The issue of trust building (close relationships) may be more critical between industrial partnerships then public-private relationships. This is because this last kind of partnership is usually based on sharing complementary resources (Pfeffer and Salancik, 1978).

A number of additional issues do need to be investigated. We have only highlighted some major characteristics. Internal R&D experience, technical experiences, and additional complexity issues are all arenas that can be more fully investigated. Discriminating between long term and short term efficiency and efficacy can also be investigated. There is still difficulty in measuring long term and qualitative performance measures. For example, improving “quality of life” is an efficiency measure that cannot be easily determined, nor measured, but clearly is something of great importance to PRCs. In addition, a number of internal and external issues such as cultural differences between the partners, differences in their products and nature of work, or some unexpected development such as reorganizations, mergers and acquisitions, and economic downturns, may all impact intersectoral relationships. Evaluating and relating these issues with performance is another direction to pursue.

Overall, the complex and interrelated nature of the factors here impairs any simple explanation of the public and private R&D partnership's performance. However, some clarification and significant discrimination between good and poor performance appeared on a number of factors. Policy makers to determine what is feasible and controllable in identifying CPs for financing and support should further investigate these major factors. In addition, generalizations to other countries and PRC types cannot necessarily be made without further investigation.

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