How do Recombinative Capabilities and Technological Proximity Influence Innovative Performance? A Study on the ICT sector

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Abstract

From an evolutionary perspective of the industrial system, firms' ability to recombine diverse knowledge domains is considered to be an important determinant of innovative capabilities. In addition, the literature on strategic alliances emphasizes the critical role of technological proximity between a firm and its alliance partners, in accessing knowledge beyond its boundaries. In this paper, we investigate the joint effect of recombinative capabilities and technological proximity between firms on the firms' innovative capabilities. Through a panel data analysis of 71 ICT firms, we find that recombinative capabilities have a positive effect on innovation. In addition, our results reveal a curvilinear relationship between technological proximity and innovative capabilities. Finally, the results show that recombinative capabilities and technological proximity with alliance partners are complementary mechanisms in innovation.

KEY WORDS: recombination, innovation, strategic alliances, ICT

1. Introduction

In recent decades, increasing product complexity and rapid innovation in knowledge intensive industries have been accompanied by richer technological opportunities to recombine knowledge in different configurations. From an evolutionary perspective of the industrial system, recombination of knowledge is a central process in innovation (Schumpeter, 1934; Nelson and Winter, 1982) which depends on a complex interplay between economic actors, artifacts, ideas and it has a central role in the evolution of technologies (Arthur, 2009; Antonelli et al. 2010).

Innovative capabilities of firms depend both on their internal capabilities and their external relationships with other actors in the economy. Stated differently, firms access complementary skills and knowledge through various forms of relationships with other organizations. Although these collaborative relations have been studied from a variety of perspectives in innovation studies, one of the questions which received relatively less attention is, how recombinative capabilities of firms and their alliance portfolios affect innovative capabilities jointly.

The aim of this article is to explore the extent to which internal recombinative capabilities and external knowledge search processes of the firm are complementary. As it is used in this paper, *recombination* refers either to the combination of elements which were previously unconnected, or finding new ways of combining elements which were already associated (Nahapiet and Ghoshal, 1997). Recombination rests on the ability to maintain variety (Weitzman, 1998). Recombination is related with the internal organization of knowledge, and it measures the extent to which the firm can creatively combine different domains of knowledge in the innovation process. On the other hand, the concept of external knowledge search distinguishes between local search and distant search mechanisms (Stuart and Podolny, 1996). The question that we address is, how do the recombinative capabilities, and a firm's external knowledge search activities jointly shape innovation capabilities?

Our study differs from the previous studies in several ways. In the literature, in-house innovation capabilities usually focus on the firms' R&D capabilities, and a common question addressed is how it interacts with external relationships of the firm. Our focus in this paper is on recombinative *competencies* of firms influence the production of innovative capabilities measured with patents, which has been less studied on an empirical level. The study draws a distinction between local and distant search in accounting for the external alliances of firms. In doing so, we refer to the literature which addresses the exploitation and exploration dimensions of organizational learning through the firms' alliance portfolio (Rothaermel, 2001; Lavie and Rosenkopf, 2006; Phelps, 2010). Although the complementarity between local search and distant search is a rich field of study under the ambidexterity hypothesis (Tushman and O'Reilly, 2004), to our knowledge, how they interact with recombinative capabilities is not studied before.

To explore these issues empirically, we focus on the ICT sector. Some of the reasons behind this choice are as follows. Firstly, ICT sector is characterised by rapid technological and structural change. In addition, the complexity of the technological base implies the critical role of complementarities between firms, and the importance of technological diversification to ensure competitive advantage (Rao et al. 2004). In order to estimate how recombination and alliance portfolios influence innovative capabilities, we analyse panel data of patents granted to 71 ICT firms between the years 1995 and 2003. We collect data from different sources including the EPO (European Patent Office), the DTI BIS R&D (Department for Business Innovation and Skills) and the CATI (Cooperative Agreements and Technology Indicators) databases. In this way, we construct an original database of worldwide ICT firms which have highest levels of R&D spending.

The paper is organized as follows. Section 2 presents the theoretical background. It relies on the Schumpeterian notion of innovation to explain the role of recombination in the innovation process. Additionally, we explore the literature on the strategic alliances and learning in order to present the article's hypotheses on the ways in which external alliance strategies of firms interact with their internal recombinative capabilities. Section 3 explains the data and measures used in the empirical investigation. The empirical results are discussed in Section 4. Some concluding remarks follow.

2. Theoretical Background

A largely established view in the management literature underlines the complementary nature of internal capabilities and external collaboration (Mowery and Rosenberg, 1989; Arora and Gambardella, 1994; Powell et al, 1996; Rigby and Zook, 2002; Cassiman and Veugelers, 2006). In order to summarize the underlying reasons behind this complementarity, it is useful to quote Powell et al. (1996) who state that:

> "Internal capability is indispensable in evaluating research done outside, while external collaboration provides access to news and resources that cannot be generated internally (Nelson, 1990). A network serves as a locus of innovation because it provides timely access to knowledge and resources that are otherwise unavailable, while also testing internal expertise and learning capabilities" (Powell et al., 1996: 119).

The complementarity perspective explains how firm-specific internal innovative capabilities are associated with higher competitive advantage, when they are implemented together with an external knowledge acquisition strategy. The role of absorptive capacity in this process is critical, whereby higher in-house R&D investments improve the way firms acquire and build upon the knowledge which they access from outside (Cohen and Levinthal, 1991). An inter-firm network is usually taken as a platform in which different fields of specialization enable not only rapid access to different knowledge domains, but also result in increased opportunities for building internal capabilities through recombination of external knowledge with internal competences (Powell et al, 1996).

While R&D capabilities are critical in absorbing the knowledge accessed externally, creative use of the acquired knowledge rests on the firms' ability to recombine it with its pre-existing knowledge base. In order to explore the recombination process, we build upon the Schumpeterian notion of innovation in the next section. Then, we investigate the relation between technological proximity with partners and innovation. Finally we explore how these two mechanisms interact with each other in the innovation process.

2.1 Recombinative Capabilities of the Firm

According to the evolutionary perception of the industrial system, recombination through the synthesis of diverse technical domains is central in the innovation process (Schumpeter, 1934; Gilfillan, 1935; Nelson and Winter, 1982; Basalla, 1988; Van den Bergh, 2008; Arthur, 2009). Recombination relies on the reconfiguration of the internal competencies in a novel way. More precisely, recombination refers either to the combination of elements which were previously unconnected, or finding new ways of combining elements which were already associated (Nahapiet and Ghoshal, 1997).

The innovative performance rests partly on the extent to which the firm generates variety internally and externally. Previous studies have found that, technological diversification can increase the innovative potential (Fleming, 2002; Miller et al., 2007) through maintaining the availability of a broader set of alternative recombination paths (Weitzman, 1998; Fleming, 2002; Carnabuci and Bruggeman, 2009). In explaining the relation between variety and innovation, the mechanism of recombination is frequently employed. Termed as "recombinant growth" by Weitzman (1998), it is accepted that creative combinations are more likely when there are a wider set of elements to be recombined. Consequently in the literature, recombination is usually assumed to be equivalent to innovation, and one of its sources is taken to be variety.

It is important to note that recombination capabilities are largely firm-specific (Kogut and Zander, 1996; Galunic and Rodan, 1998; Miller et al., 2007) as they are embedded in firms' internal routines in storing, retrieving and processing knowledge, in a way independent from the existing *level* of technological diversification of the firm.[1] In other words, firms differ from each other in the level and extent to which they can make use of diverse technological domains. This also depends on the extent to which firms can manage the "paradox of capabilities" (Srivastava and Gnyawali, 2011) which refer to the barriers the firms face in accessing variety from outside, because of competency traps which prevent them from recognizing knowledge domains with high potential of novelty, and risk of leakage of their valuable knowledge sources to the outside. In addition, recombinative capabilities at the firm level will depend on the extent of complementarities among the assets of the firm, and which mechanism the firm selects in accessing resources (Hess and Rothaermel, 2011).

If recombinative capabilities are largely firm-specific, the next question is whether they are associated with better innovative capabilities? In other words, are firms which can better make use of variety more innovative? The first hypothesis is concerned with testing this alleged positive relationship between recombination and innovation.

[1] Variety increases the chances of novel recombination, yet this ability is largely firm-specific. Stated differently, two firms with the similar knowledge bases may have different capabilities to make use of it.

It is also possible to argue that there is a limit to the positive effect of recombination on innovation as diminishing returns to recombination might emerge (Weitzman, 1998; Antonelli et al. 2010). In fact, the positive effect of recombination on innovation will depend largely on the *rate of change* of variety in the firm (Garcia Vega, 2006; Van den Bergh, 2008). As knowledge is localized, the rate at which the technical variety in a firm changes is slow, because the established and routinized learning processes inhibit the rate at which firms can absorb new knowledge in new technical domains, and because of the localized nature of learning (Antonelli, 2006). Integration of new knowledge can entail diminishing returns if it requires recombination of excessive variety (Antonelli et al., 2010). Thus further possibilities of innovation, drawing upon the slowly changing current technical domains will be exhausted, even tough the firm may be equipped with high recombination capabilities. Therefore we propose that,

Hypothesis 1: Firms with higher recombinative capabilities have higher innovative capabilities.

Hypothesis 2: There is an inverted-u relation between recombination and innovation capabilities.

2.2 External Linkages of the Firm and Innovative Performance: The Role of Technological Proximity

Recent studies show in various industrial contexts that the characteristics of the portfolio of firms' alliance partners influence their performance. Organizational learning (Phelps 2010; Lavie et al., 2011) and capability transfer (Mowery et al., 1998), have been important mechanisms underlying this effect since one of the important motives behind alliances is learning (Powell et al., 1996) through local and distant knowledge search (Stuart and Podolny, 1996).

As March (1991) defines, exploration dimension of organizational learning refers to "experimentation with new alternatives", and the exploitation to the exercise of "refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85). Both exploration and exploitation should be taken as a knowledge search processes, and they happen both within and outside the firm boundaries. In other words, search processes can be described as the firms' struggle to identify, select, and learn from knowledge that can be both beyond their boundaries, as well as internal. Whether firms treat these to be substitutes or complements has been a matter of debate in the literature (Lavie et al.,2010; Lavie et al., 2011).

Alliance portfolios can be taken in relation to diversity of partners (Jiang, 2010; Lin et al., 2010; Phelps, 2010), foreignness of alliance partners (Lavie and Miller, 2008), exploration vs. exploitation alliances (Lavie and Rosenkopf, 2006, Yamakawa et al., 2011) technological proximity between the partners (Mowery et al. 1998; Vanhaverbeke et al., 2009). A growing body of literature investigates exploratory and exploitative dimensions of firms' alliance portfolios, and their effect on performance. The results of this literature reveal that partner diversity is better for explorative innovation (Lavie and Rosenkopf, 2006; Phelps, 2010) because it increases the extent to which firm accesses non-redundant knowledge. Some other studies find that rather than the diversity of partners, the extent to which partners are technologically distant from the firm determines its explorative innovation (Nooteboom et al., 2007). For example, Ahuja and Katila (2001) find that recombinative search is better carried out with distant partners.

Fairly increasing amount of studies detect a curvilinear relation between the technological proximity between two firms and the extent of transfer of capabilities (Schoenmakers and Duysters, 2006; Nooteboom et al., 2007; Gilsing et al., 2008; Cowan and Jonard, 2009). Moreover, this proximity increases as firms collaborate with each other (Mowery et al., 1998). The underlying logic in this construct is that, when firms are too close in the knowledge space, they have few to add to each others knowledge, when they are too far, they cannot access each others knowledge base, and learning is limited. The next question that we address in this paper is concerned with how technological distance between the firm and its partners influence the firm's innovative capabilities? Based on the above literature on the optimal cognitive distance, we propose that, both high levels of technological overlap and low levels of overlap with alliance partners restricts the firm's innovative capabilities because there can be limited knowledge that the firm is able to acquire from outside.

Hypothesis 3: There exists an inverted-u relation between the innovation capabilities of a firm, and the average technological proximity between itself and its alliance partners.

The next question that we turn to is related with the interaction effect between internal recombinative capabilities and the alliance portfolio of the firm.

2.3. The Joint Effect of Recombinative Capabilities and Partner Proximity

While strategic alliances are usually considered as a source of variety (Rosenkopf and Almeida, 2003), and that exploratory search processes are associated with the ability of the firm to access variety (March, 1991; McGrath, 2001), whether the firm can absorb this new knowledge and build upon it through recombining with its existing knowledge domains depends on internal routines, skills and capabilities of the firm (Kogut and Zander, 1996). For increased innovative capabilities firms should be able to capture the value of the external knowledge and integrate it within, which depends on the "firms' ability to recognize the value of new, external knowledge, assimilate it, and apply it to commercial ends" (Cohen and Levinthal, 1990). Consequently, a range of studies look at how absorptive capacity and the network position of the firm jointly shape innovative capabilities. For example, firms with higher absorptive capabilities can make better use of central positions in networks (Tsai, 2001), and they can deal better with heterogeneous information (Shipilov, 2009).

Exploratory alliances refer to search processes which are highly risky, but at the same time they can yield higher returns compared to deepening of the knowledge base through exploitative search processes. Therefore, for increased innovative capabilities, firms need to explore new knowledge which may transcend beyond local search. When firms are not able to do so, because of their routines favoring local search, competency traps can result (Cohen and Levinthal, 1990; Leonard Barton, 1992). Indeed, despite potential benefits of exploratory alliances, research shows that firms search narrowly within their existing technological domains (Helfat, 1994; Stuart and Podolny, 1996) in the form of exploitative alliances, which connote technological proximity between partners. In this context, Srivastava and Gnyawali (2011) stress the paradox of capabilities; while partnerships with resource-rich firms can improve the firms' capabilities for radical innovations through accessing variety, competency traps and possible leakages of valuable knowledge can be barriers in the innovation process.

As far as the complementarities between internal resources and external relationships are concerned, it is possible to find in the literature that it largely depends on the context of analysis, like which types of resources are taken, or how complementarities are defined. For example, focusing on two mechanisms of resource recombination, as recruitment of star scientists, and strategic alliances, Hess and Rothaermel (2011) state that complementarities among assets depend on their positioning in the value chain; assets that are closer to each other are substitutes, the ones that are distant in value chain have higher complementary value. Lavie and Drori (2011) find that, the complementarity depends on the *level* of collaboration, and the partner type. For example, when there is excessive collaboration with academic partners, it can complement the internal resources of the firm in knowledge creation.

In this study, we take the recombinative capabilities of firms to be largely determined by internal routines. A firm with high recombinative capabilities connotes one that has appropriate mechanisms to search for innovative combinations in its pre-existing knowledge domains. They are the result of, and are maintained by the internal routines, procedures, processes, which characterize the innovation environment. Previous studies have documented internal mechanisms as important in recombination (Galunic and Rodan, 1998; Miller et al., 2007).

While recombinative capability connotes the ability to synthesize distinct, and possibly diverse knowledge domains, local search processes underlie refinements in a specific domain. Both processes are highly relevant in the problem solving activities in the firm, in terms of searching for alternative solutions, and selecting the useful ones in the technology space (Arthur, 2009). In other words, problem solving is a critical capability in innovation (Vincenti, 1990) which requires both a profound understanding of the relevant domain and a capacity to look at the distant technology landscape in selecting alternative solutions. In this sense, for a firm with high recombinative capabilities whose internal routines are oriented towards operationalization of variety, exploitative alliances (which are usually with firms which have a high technological overlap with the focal firm) can have a complementary effect, in terms of refinements in each of the diverse technology domains. In addition, such refinements are usually associated with incremental innovations which can be critical for competitive advantage of incumbent firms (Banburry and Mitchell, 1995). Accordingly we propose that:

Hypothesis 4: There is a positive interaction effect between technological overlap between the firm and its partners, and its recombinative capabilities, in their effect on innovation capabilities.

3. Method and Data

The model applies the above theoretical framework to the analysis of the ICT sector. There are several reasons behind the selection of this sector as a suitable context to test our hypotheses. ICT is one of the fastest growing sectors of the economy, accompanied by rich technological opportunities, as also revealed by the increasing number of patent applications during the recent decade (Corrocher et al., 2007). The development of the ICT sector has been characterized by a process of continuous and rapid technological change where radical innovations enable incremental innovations (Bresnahan and Malerba, 1999). In this sense, it represents an example of Schumpeterian gale of innovation characterized by growing convergence and the integration among a variety of localized innovations, generated within different industries and firms. Technological convergence has been driven by the introduction of different innovations such as Internet services, Asynchronous Digital Subscriber Lines (ADSL), and VoIP (Fransman, 2002; Cecere, 2009).

One of the most important characteristics of the ICT industry is that, the dominant input in production is knowledge. Because knowledge can be inexpensively reproduced (expansible) and it is non-rival (its use by one party does not exclude others from using it), an original design can be re-used in meeting different markets, which is a source of economies of scope (Steinmuller, 2007). Knowledge recombination is essential in the industrial dynamics and it is characterized by a sequence of highly selective process of exploration (Corrocher et al., 2007). The development of the ICT sector has been characterised by the recombination of a variety of knowledge domains, stemming from different technologies (Van den Ende and Dolfsma, 2005; Antonelli at al, 2010).

3.1 Data

We collect data on 71 ICT firms that are recorded by the DTI database BIS (Department for Business Innovation and Skills) during the period 1995-2003. This database collects data on the firms that have the highest R&D expenditure worldwide. We collect comprehensive information on the most important determinants of firm’s innovative capabilities. The data were obtained from different sources including the EPO database (PATSTAT), CATI (Cooperative Agreements and Technology Indicators) database, bnet.com website and firms’ own websites. CATI covers around 19,000 technology based alliances of nearly 9500 firms.

The data is systematically collected since 1986 (although some of the alliances date back to end of 1800s), and it is one of the most widely used databases as far as technology based strategic alliances are concerned. Although data maybe incomplete, it is considered as one of the most dependable data sources in this field (Schilling, 2008). For each firm in our database between 1995 and 2003, we collected the technology based cooperative agreements that the firm was involved in. We came up with a total of 71 ICT firms, operating in Electronics, telecommunications and computer sectors, with high technical competences (jointly considering R&D and patent counts). In this way, we included a total of 349 070 granted patents taken by these firms during the period 1995-2003.

In order to control for alternative determinants of patenting behavior which have been identified in the previous literature we include a broad set of control variables in our regression. In the following section, we detail the variables contained in our dataset before presenting some descriptive statistics.

3.1.1 Patent information

The primary goal of this paper is to analyze how technological proximity with partners and their recombinative capabilities jointly affect the innovative competencies of ICT firms. Because we are investigating the innovative capabilities, we take the number of patents of the focal firm to be the dependent variable. [2] Accordingly, we gathered variables that measure the firm's patent portfolio such as number of patents and the technological fields of the patent. For each firm in the dataset, we collected the patents granted by the USPTO in the mentioned period. In addition, we collect the patents granted to the partner firms which were involved in one or more alliances with the focal firm[3]. Patents were searched using the firm name, along with familiar abbreviations, and evident variations in spelling of firms' names. Below we explain how recombinative capabilities and technological proximity is measured.

3.1.2 Recombinative Capability

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[2] Although patents are usually considered to be a good source of measuring innovation input, patent data have some limitations (Griliches, 1990; Silverman, 1999).

[3] We collect also the technological fields of the firms (that are not necessarily included in our sample) involved in a strategic alliance with the firm in our sample.

We take recombinative capability as the independent variable in the regressions. Each patent document includes the relevant technology codes related with the subject matter of the patent, which is given by the 8-digit International Patent Classification (IPC) code. In this study, the main and secondary IPC codes of patents are used to derive measures of recombinative capabilities and technological diversification. To measure the recombinative capability of a firm, we take into account its propensity to combine different technology fields in a single patent document. The more different types of technology fields a given patent extends to, the higher is the recombinative value of the patent. For this purpose, we converted all the IPC codes of patents in the sample into one of 30 main technology fields (Schmoch, 2008). [4] To measure recombinative value of a patent, we use the Blau index (1977) which is traditionally used to measure diversity in a population in sociological studies. Here, the recombinative value of a patent *j* taken by firm *i* is given by:

$$b_{ij} = 1 - \sum_k a_{ik}^2$$

where a_{ik} is the proportion of technology field k in patent j. Smaller values indicate the dominance of some technology fields over the others in the patent document. On the other hand, high values of the index reflect a higher variety in technology fields which reflects higher recombinative capabilities. Therefore, the recombinative capability of firm i in year t is given by the average of the BLAU index for the patents taken during that year:

$$\mathrm{Re}\,com_{it} = \frac{\sum_j b_{ij}}{P_{it}}$$

where P_{it} is the total number of patents taken by the firm *i* in year *t*. In the regression we consider the recombination index lagged of one year as it permits to consider the reverse causality.

3.1.3. Technological Proximity with Alliance Partners

Average knowledge overlap between the firm and its partners (as evident from the patent portfolio) measures the extent to which two firms are proximate in the knowledge space. By knowledge base of a firm we refer to the main technology fields that the firm is active in a given year and the intensity of its patenting in this field. Therefore, the knowledge base of the

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[4] The mapping between IPC codes and 30 technology fields is based on the study by Fraunhofer Gessellschaft-ISI (Karlsrube), Institut National de la Propriété Industrielle (INPI-Paris) and Observatoire des Sciences et des Techniques (OST, Paris) .

firm measures the breadth of the knowledge as revealed by the range of different technology fields that a firm obtains into patents. In addition, the knowledge base reveals how deep the firms knowledge is, in a given technology field, by measuring the proportion of firm's patents which belong to a given technology field. In this sense, technological overlap between two firms captures the extent to which their breadth and depth of competences are similar to each other.

For each of the firms in the database, we identify all the firms that the firm had an alliance with. EPO PATSTAT patent database was then used to collect the patents granted to all the partner firms in the years in which it had an alliance with the firm. In this way we included a total of 2980 alliances, for a total of 1200 firms. We use the cosine index (Breschi et al., 2003) to calculate the extent of overlap between the firms' patent portfolio, and each of its partners. Here we assume that the more is the overlap between two firms in terms of the breadth and depth of their patent portfolio, the more proximate they are in the technology space. Cosine index that we define TechProx between firms i and j is calculated in he following way:

$$TechProx_{ij} = \frac{\sum_{k=1}^{30} a_{ik} a_{jk}}{\sqrt{\sum_{k=1}^{30} a_{ik}^2}\sqrt{\sum_{k=1}^{30} a_{jk}^2}}$$

where, a_{ik} refers to the proportion of technology field k in all the patents taken by firm i in a given year. Obviously, $TechProx_{ij}=1$ indicates that the two firms are exactly the same in terms of their technological profile, and if there is no common technology field between the patent portfolios of two firms, $TechProx_{ij}=0$. Therefore, high cosine values indicate increased overlap between the knowledge bases of two firms, in terms of similarity.

The independent variable that we use for the alliance portfolio of firm i is the average of its technological distance with its alliance partners in time *t-1* (lagged of one year). In the literature on inter firm networks, the diversity of partners is taken as an important determinant of innovative capabilities of firms (Lavie and Rosenkopf, 2006; Phelps, 2010). Surprisingly, our dataset shows that firms are quite consistent in a given year, in terms of their strategy of partnership. In other words, there is little variety in the overlap of a firm with each of its partners. This is why, an average distance over all firms can be taken as a measure of the firms' partner selection strategy for a given year. In order to estimate the complementarity between the recombination capabilities and technological proximity, we include in the regression the interaction effect of these two variables.

3.1.4 Firms' characteristics

We obtained detailed information on yearly basis from the DTI (BIS- Department for Business Innovation and Skills) R&D database which provides detailed data on the largest firms in the world. Firstly, we include the annual R&D expenditure of each firm in millions of pounds, and we instrument the variable considering the 1-years lagged R&D expenditure deflated by GDP price index[5]. R&D expenditure measures both the effect of firm size and the innovation input. Smaller firms can have more willingness to exchange internal information. Larger firms are expected to have larger financial means with respect to smaller firms. However, large firms can have some rigidity which hampers the explorative knowledge activities (Gilsing et al., 2008). Secondly, we include dummy variables indicating the company headquarters which allows to take into account the difference among the different continents; namely Europe (EU), USA (US), Japan (JAPAN) and other countries (OTHER). The reference variable in the regression is the dummy variable EU. Additionally, we consider the number of alliances that firms undertake to take into account the learning effect of being involved in large number of strategic alliances.

3.1.5 Industry classification and age of the firms

In addition to the variables described above, we control for industry differences and firms' age in the patenting behavior. We obtained this data on the firm's website or on the bnet.com website. Based on the NAICS code of the firms that we collected in the website of the firms, we create a set of dummy variable based on the 3-digit NAICS code that consider the different group of firms namely semiconductors, producers of Machinery Manufacturing and Printing and Related Support Activities and so forth. These categories are not a precise assignment of the activities of the firms but it can capture some sector specific characteristics.

3.2 Descriptive statistics

[5] As we have some missing variables in the measure of R&D expenditure, the sample is reduced to 245 observations.

Before presenting the estimation results in Section 4, Table 1 presents some descriptive statistics of the sample. In total, our sample contains 71 R&D intensive firms which have at least one strategic alliance agreement recorded in the CATI database. The smallest firm has 600 employees and the largest 668000 employees. Annex A presents the correlation matrix of the all variables in the sample. Table 2 reports the break down statistics of variables according to industrial sectors. Approximately 50% of the firms in the sample are established in USA, about 24% of the firms are based in Japan and only 16% are located in Europe.

Table 1. Descriptive statistics

Variable	Description	Mean	Std. Dev.	Min	Max
Patent	Number of total patents granted to firm i in time t innovative competencies	344.660	569.628	1	4158
Recom $_{it-1}$	Measured by the Blau index, for a single patent. The average is taken over all patents of firm *i* in time *t-1*	.0364	.0347	0	.275
Recomsq $_{it-1}$	Recombination in square	.0025	.0060	0	.076
Techprox $_{it-1}$	Technological proximity with alliance partners is intended to measure the average knowledge overlap between the firm *i* and its partners in time t-1	.5697	.2500	0	.993
Techprox in sq $_{it-1}$	Technological proximity in square	.3868	.2633	0	.986
Recom $_{it-1}$ *TechProx $_{it-1}$	Interaction effect Recombination index multiplied by Technological Proximity-Cronbach method	.0203	.0185	0	.1284
$R\ \&\ D_{it-1}$	Natural log of the deflated R&D investment of firm i in time t-1 in £m	6.152	1.648	-1.251	9.285
Nb of alliance	Number of alliances per year	1.706	3.292	0	22
Age	Based on the establishment year of the firm	52.35	36.53	11	163
Agesq	Age in square	4073.4	5297.3	121	26569
NAICS 334	Industrial segment of the firm NAICS 334	.5054	.5004	0	1
NAICS 541	Industrial segment of the firm NAICS 541	.1268	.3330	0	1
NAICS 32;33	Industrial segment of the firm NAICS 32; 33	.0970	.2962	0	1
NAICS 511-8	Industrial segment of the firm NAICS 511;8	.1127	.3164	0	1
USA	Dummy variable sets to one if the firm is based in US	.5352	.4991	0	1
JAPAN	Dummy variable sets to one if the firm is based in Japan	.2394	.4271	0	1
Other	Dummy variable set to one if the firm is based in other countries	.0704	.2561	0	1

Table 2. Detailed data on firms by NAICS segment

NAICS category	Firms	Examples
Professional, Scientific and Technical Services (NAICS 541)	9	3COM, ALCATEL, GEMPLUS, INFINEON TECHNOLOGIES
Computer & electronic product manufacturing (NAICS 334)	36	Atlmel, LG Eletronics, Nokia, Sony, Symantec
Office Machinery Manufacturing and Printing and Related Support Activities (NAICS 32; 33)	7	Avid Technology, Dainippon Screen MFG, Xerox

Producing and distributing information and cultural products; Transmission and processing of data or communications (NAICS 511-8)	8	Ericsson, I2 Technologies, Oracle
Professional, Scientific, and Technical Services Other NAICS[6]	11	3M, Amazon, IBM, Siemens

3.3 The Model

The dependent variable is a count variable which corresponds to the number of patents granted by firm i in year t. Poisson regression is a baseline model for count data (Hausman et al., 1984). The results of the Poisson specification compared to negative binomial model shows that the standard errors reflecting efficiency gain due to better model identification (Cameron and Trivedi, 2009). Annex B details the results of the negative binomial estimation. Additionally, the Hausman test confirms the use of random effect. We centered the covariates recombination and technological proximity on their means before computing the interaction term (e.g., Gronbach, 1987). The Poisson estimating equation is specified as follows:

$$Patent_{it} = \alpha + \mathrm{Re}com_{it-1} + \mathrm{Re}comsq_{it-1} + Tech\,\mathrm{Pr}ox_{it-1} + Tech\,\mathrm{Pr}oxsq_{it-1} + \mathrm{Re}com_{it} * Tech\,\mathrm{Pr}ox_{it} + RD_{it-1} + \delta_i + \varepsilon_{it}$$

with $Patent_{it}$ being the number of patents of the firm *i* in time t; δ_i are set of *i*th firm characteristics which measures the firm-specific heterogeneity and ε_{it} represents the error which is assumed to satisfy the usual regression model conditions.

[6] Reference variable in the regression

Table 3. Results of the Poisson Panel estimation: Dependent variable innovation capabilities

	Poisson Fixed Effect (1)	Poisson Random Effect (2)	Poisson Random Effect (3)	Poisson Fixed Effect(4)	Poisson Random Effect (5)
Recom $_{it-1}$	2.249*	2.366*	7.892 ***	7.954***	7.924***
	(1.283)	(1.282)	(1.696)	(1.696)	(1.695)
Recomsq $_{it-1}$	-63.488***	-64.869***	-105.722***	-107.126***	-107.152***
	(7.292)	(7.294)	(10.758)	(10.786)	(10.791)
TechProx $_{it-1}$	1.860***	1.866***	1.687***	1.692***	1.694***
	(0.104)	(0.104)	(0.111)	(0.111)	(0.111)
TechProx sq $_{it-1}$	-1.710**	-1.716***	-1.454***	-1.457***	-1.458***
	(0.080)	(0.080)	(0.084)	(0.084)	(0.084)
Recom $_{it-1}$ *TechProx $_{it-1}$	8.096***	8.150***	3.981**	4.004**	4.003**
	(1.611)	(1.610)	(1.965)	(1.964)	(1.963)
$R \& D_{it-1}$			-0.055***	-0.043***	-0.042***
			(0.015)	(0.015)	(0.015)
Nb of alliances			0.007 ***	0.007***	0.007***
			(0.001)	(0.001)	(0.001)
Age					0.039**
					(0.017)
Agesq					-0.000
					(0.000)
NAICS 334					-0.493
					(0.589)
NAICS 541					0.296
					(0.887)
NAICS 32;33					-0.909
					(0.700)
NAICS 511-8					0.047
					(0.752)
USA					-0.096
					(0.705)
JAPAN					0.562
					(0.727)
OTHER					1.356
					(0.919)
_cons		4.452***	4.717***		3.293***
		(0.168)	(0.215)		(0.942)
lnalpha _cons		0.613***	0.699***		0.494***
		(0.140)	(0.142)		(0.145)
Time dummies	Yes	Yes	Yes	Yes	Yes
Wald Chi 2	9056.87	9060.96	8682.67	8684.00	8707.30

N	295	295	249	249	249

Standard errors (in parentheses) adjusted for clustering on id –Firms
Level of significance * p<.10, ** p<.05, *** p<.01

4. RESULTS

Table 3 presents the results for the estimation of innovative capabilities measured by the firms' number of patents. To check the robustness of our estimation, we perform different estimations. The first two regressions report the baseline models. Regression 1-4 estimate the equation using only time-varying variables. Regression 1 and 4 use the fixed effect estimators and Both Regression 2 and 3 use the random effect estimators. Regression 5 includes all variables. Additionally, we introduced annual dummy variables in all estimations to consider changes over time, they can capture the increasing importance of innovative competencies or changing institutional conditions which favor the creation of innovative competencies.

The results corroborate the Hypothesis 1, confirming positive relationship between recombinative and innovative capabilities at the firm level. Firms that have high recombinative competencies are more innovative. Additionally, we investigate the functional relation between innovative performance and recombinative capabilities. The results show that there is an inverted-U shaped function of recombinative capabilities corroborating the Hypothesis 2; the linear term of recombinative measure has a significant and positive effect and the quadratic term a significant and negative effect. In other words, recombinative capabilities positively affect the innovative performance as firms can fully exploit their internal knowledge diversity. However, recombinative capabilities have positive effect upon a certain point which shows that diminishing returns can set in, as it is already demonstrated in the literature (Antonelli et al. 2010).

Similarly, the results confirm the Hypothesis 3 which states that there is an inverted u-relation between the innovative potential of a firm, and the average technological proximity between itself and its alliance partners. In other words, innovation performance is a parabolic, inverted-U shaped function of technological proximity measure as revealed by the negative and significant quadratic firm.

As far as Hypothesis 4 is considered, the interaction effect between technological proximity (between the firm and its partners) and firms' recombinative capabilities positively influence the innovative capabilities showing the existence of complementarities between reconfiguration of internal knowledge and technological proximity with partners. Although internal knowledge dynamics is useful in terms of increasing the absorptive capability of the firm in making use of the knowledge it accesses from outside, cooperation with other firms can favor the access and the exploitation to the knowledge beyond its boundaries.

As far as control variables are considered. The result shows a negative and significant effect of R&D expenditure on the creation of innovative competencies. This counterfactual result can be justified with the fact that our sample is composed of large firms in the ICT sectors so the largest firms have some inertia to knowledge creation. There is no particular effect of country and sector variables. The age seems to influence the innovative capabilities showing learning process for more ancient firms.

5. Concluding Remarks

The aim of this paper is to advance our understanding on how recombination of knowledge and technological proximity with alliance partners can influence innovative capabilities as measured by patents. The underlying motive in the paper is to understand whether firms with higher recombinative capabilities can better make use of their external relations in the innovation process. In the estimation, we jointly included both recombinative capabilities of firms and their average technological proximity with their partners. Our results reveal that both recombinative capabilities and proximity with partners influence the innovative capabilities of firms in the ICT sector.

We take recombinative capability as one of the essential determinants of innovative capabilities. This is in accordance with the Schumpeterian notion of resource combinations. Several mechanisms can explain how recombination positively influences innovation. Accessing new knowledge which is different from the firms' own domains is not necessarily sufficient for innovative capabilities; rather, it is the firms' ability to assimilate this new knowledge (or its absorptive capacity); and secondly, the firms ability to convert this knowledge into new resource combinations are critical capabilities in innovation. Although internal R&D is useful in terms of increasing the absorptive capability of the firm, in making use of the knowledge it accesses from outside, external linkages can help the firm access, and build upon the knowledge beyond its boundaries (Cohen and Levinthal, 1990).

Accordingly, the second mechanism that we focus on is the portfolio of strategic alliances of the firm. Research on inter-firm networks has deepened our understanding of the mechanisms behind their formation and their performance effects. Firms in a range of industries are involved in various forms of cooperative agreements, and one of the most important motives behind collaborative relations is organizational learning. In this paper, we focus on the technological proximity of the firm with its partners. Firstly, we detect a curvilinear relation between the proximity of the firm to its partners, and the firm's innovative capabilities. Similar results have been obtained in various contexts before, especially in terms of the learning capabilities of firms. We also show that the effect of recombinative capabilities on innovation is mediated by the technological proximity with partners. Indeed, we detect a complementary effect, such that better recombinative capabilities are reflected in innovation for firms who are technologically proximate to their partners.

Finally, there are a few points about the paper which should be underlined in interpreting our results. We do not take into account other internal organizational variables, which can shape recombination process. For example, management design, organizational culture, institutional context, or the structure of networks among inventors in the firm can have a significant impact on recombination and innovative performance. This is a research avenues that needs to be analyzed. A second point is related with approximating innovative capabilities of firms with patent data. Although there is a very rich literature which uses this approximation, one should be careful in interpreting the results. In particular, high patenting propensity may not be a sign of high innovative capabilities in all sectors. In this sense, sectoral differences in patenting propensity are quite significant. Focusing on the ICT sector, partly alleviates this problem, since it is a sector in which patenting propensity is very high. Finally, this article focuses on ICT sector, but it would be interesting for future research to address how recombination and proximity interacts in other sectors to see the extent to which sector specific knowledge regimes determine the role of recombination, proximity and how they interact.

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Annexe A. Correlation matrix

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Patents	1	1.0000																
Recom $_{it-1}$	2	0.0024	1.0000															
Recomsq $_{it-1}$	3	-0.1250	0.9054	1.0000														
TechProx $_{it-1}$	4	0.2122	-0.0578	-0.0836	1.0000													
TechProxsq $_{it-1}$	5	0.1545	-0.0996	-0.1160	0.9634	1.0000												
Recom $_{it-1}$ *TechProxsq $_{it-1}$	6	0.1229	0.8142	0.7338	0.4096	0.3704	1.0000											
$R\ \&\ D_{it-1}$	7	0.6226	-0.0235	-0.1215	0.2730	0.1943	0.1063	1.0000										
Nb of alliances	8	0.6899	-0.0600	-0.1431	0.2491	0.1938	0.0768	0.5854	1.0000									
Age	9	0.3010	0.1861	0.1333	-0.0662	-0.1090	0.1329	0.4246	0.2260	1.0000								
Agesq	10	0.2204	0.1611	0.1229	-0.0997	-0.1311	0.0817	0.3297	0.1659	0.9696	1.0000							
Naics334	11	-0.0476	-0.0023	-0.0358	0.0267	0.0228	0.0184	-0.0641	0.0594	-0.1409	-0.1528	1.0000						
Naics541	12	-0.0236	0.0374	0.0422	0.1422	0.1836	0.1059	0.0265	-0.0491	0.0140	0.0037	-0.3558	1.0000					
Naics33other	13	-0.0871	0.1196	0.1510	-0.2018	-0.1791	0.0170	-0.1318	-0.1572	0.2220	0.2254	-0.3418	-0.1266	1.0000				
Naics51other	14	-0.1058	-0.1187	-0.0843	0.0268	0.0003	-0.1151	0.1392	-0.0125	-0.1550	-0.1414	-0.3964	-0.1468	-0.1410	1.0000			
USA	15	-0.0468	-0.1527	-0.1132	0.0171	0.0484	-0.0965	-0.2081	0.1494	-0.3853	-0.3636	0.1328	-0.1671	-0.0946	0.1222	1.0000		
JAPAN	16	0.1748	0.1390	0.0791	0.0027	-0.0101	0.1239	0.2360	-0.0848	0.4135	0.3430	-0.1467	0.0446	0.2619	-0.1815	-0.6455	1.0000	
OTHER	17	0.0159	-0.0208	-0.0474	-0.0421	-0.0247	-0.0383	-0.0951	-0.0404	-0.1666	-0.1588	0.2193	-0.0781	-0.0750	-0.0869	-0.2176	-0.1371	1.000

Annex B. Negative Binomial estimation: Dependent variable innovation capabilities

	NBER Random effect (1)	NBER Fixed effect (2)
Recom $_{it-1}$	8.300**	6.208*
	(4.181)	(4.100)
Recomsq $_{it-1}$	-96.104***	-80.345***
	(24.990)	(23.872)
TechProx $_{it-1}$	2.006***	1.923***
	(0.615)	(0.617)
TechProxsq $_{it-1}$	-1.785***	-1.702***
	(0.520)	(0.523)
Recom $_{it-1}$ * TechProx $_{it-1}$	9.311*	9.540*
	(5.235)	(5.254)
_cons	0.273	0.328
	(0.244)	(0.243)
ln_r _cons	-0.450***	
	(0.146)	
ln_s _cons	1.525***	
	(0.225)	
Time dummies	Yes	Yes
Wald Chi 2	150.34	147.14
N	295	295

Standard errors in parentheses

Level of significance * p<.10, ** p<.05, *** p<.01