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

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Abstract

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Abstract

Firms' ability to recombine diverse knowledge fields 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, when the firm accesses knowledge beyond its boundaries. In this paper, we investigate the effect of recombinative capabilities and technological proximity between firms, on the firms' innovative capabilities. In addition, we investigate the interaction between these two mechanisms: recombination and engagement in strategic alliances. Through a panel data analysis of 71 ICT firms, we find that firms with higher recombinative capabilities are better in terms of patenting capacity. Secondly we confirm the curvilinear relation between technological overlap and innovation capabilities. Third, we find that recombinative capabilities and technological proximity with partners are complementary mechanisms in innovation.

KEY WORDS: recombinative capabilities, technological proximity, 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, the recombination of knowledge is a central process (Schumpeter, 1934; Nelson and Winter, 1982) which depends on a complex interplay between economic actors, artifacts, and ideas, and mainly happen through the networks between them. The essential mechanism of recombination emphasizes this complex network, and shapes technological evolution through recombination of existing knowledge (Arthur, 2009; Antonelli et al. 2010).

Innovative capabilities of firms depend both on their internal capabilities, and their external knowledge access mechanisms. The internal mechanisms rely on the creative 'fresh' combination of the existing knowledge which can induce firms to diversify their knowledge (Arthur, 2007). In addition, technologies and knowledge which are complementary to the firms' competences, but which firms lack internally are accessed through alliances and cooperative agreements with other firms and research institutes. Although these issues have been studied from a variety of perspectives in innovation studies, one of the questions which has received relatively less attention is how recombination of internal competencies affects innovative activities. In the present paper our aim is to measure how internal and external sources of competences affect the production of knowledge. Firstly, we take into account the recombinative capabilities of firms. We use recombinative capabilities as a measure of the extent to which the firm can creatively combine different domains of knowledge in the innovation process. Secondly, we take into account the alliance portfolio of the firms. By alliance portfolio, we refer to the nature of the linkages between the firm and its partners, in terms of similarities in their technological profiles. The question we address is, how do the recombinative capabilities, and a firm's technological distance from its alliance partners shape innovation jointly?

In this paper, our aim is to investigate complementarity between internal innovative capabilities, and external knowledge search processes of the firm. Our approach differs from the previous studies in various ways. Most of the work on this query focus on the internal R&D capabilities, and investigate how it interacts with external alliances of the firm. In this paper, we focus on the internal *recombinative capabilities* of firms as an important capability in the innovation process. As we use it in this text, *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 second way in which this work differs from previous ones lies in considering the difference between the local and distant search in accounting for the external alliances of firms (Stuart and Podolny, 1996). 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). Finally, although the complementarities between local search and distant search is a rich field of study under the ambidexterity hypothesis (Tushman and O'Reilly,), there exists no study which looks at how the search activities interact with recombination mechanisms.

ICT industry is characterised by rapid technological and structural change where firms need to widen their competencies to ensure the competitive advantage, hence firms should deeply exploit their competencies (Rao et al. 2004). ICT is one of the fastest growing sectors of the economy, accompanied by rich opportunities for technical change, as also revealed by the increasing number of patent applications during the recent decade (Corrocher et al., 2007). 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). This creates important opportunities in the industry for the existence of a diverse range of knowledge and products. Moreover, it is one of the factors which shapes the heterogenous industrial architecture, giving rise to small and specialized firms alongside established ones, as well as an important weight of universities and research centers (Corrocher et al., 2007).

To estimate how the internal knowledge organization and external linkages influence the production of innovative capabilities in knowledge intensive business, we analyse panel data of patents of 71 ICT firms between 1995 to 2003. We collect data from different sources including the EPO, the DTI R&D and the CATI datasets. We construct an original database of ICT firms included the firms that spend more in R&D in worldwide. Firm competitiveness depends upon their capabilities to combine external knowledge to their existing competencies.

The paper is organized as follows. Section 2 relies on the Schumpeterian notion of innovation to explain the role of recombinative capabilities of firms in the innovation process. Additionally, we analyze the literature that focus on the external collaborations of the firm in order to investigate how external alliance strategy of firms interacts with its internal recombinative capabilities. Section 3 explains the data and measures used in the empirical investigation. The empirical results are discussed in Section 4. Conclusion and discussion follow.

2. Theoretical Background

The aim of this paper is to investigate how firm-specific internal recombination capabilities and the firms' external knowledge search processes jointly determine the innovative capabilities. A largely established view in the literature stresses the complementary nature of internal capabilities and external collaboration (Mowery and Rosenberg, 1989; Arora and Gambardella, 1994; Freeman, 1991; Powell et al, 1996; Rigby and Zook, 2002; Cassiman and Veugelers, 2006). Powell et al. (1996) 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 main mechanism works through absorptive capacity, whereby increased internal R&D investments improve acquiring and building upon the knowledge which the firm accesses from outside (Cohen and Levinthal, 1991). Here, an inter-firm network is taken as a platform in which different fields of specialization among firms enable not only rapid access to different knowledge fields, but also yield increased opportunities for building internal capabilities through recombination of external knowledge with internal competences (Powell et al, 1996).

To address this question, below we take a closer look at the literatures on recombinative capabilities and alliance portfolio of the firms, by reviewing the theoretical and empirical literature. Firstly, we build upon the Schumpeterian notion of innovation to explain the role of recombination in the innovation process. In the next part, we turn to the external collaborations of the firm, and investigate how local and distant search influences innovation, and how the external alliance strategy of firms interacts with its internal recombinative capabilities. Here, an inter-firm network is taken as a platform in which different fields of specialization among firms enable not only rapid access to different knowledge fields, but also yield increased opportunities for building internal capabilities through recombination of external knowledge with internal competences (Powell et al, 1996).

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 in the innovation process *(Schumpeter, 1934; Nelson and Winter, 1982; Arthur, 2009; Basalla, 1988; Gilfillan, 1935; Van den Bergh, 2008*). 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 innovative combinations are more likely when there are a wider set of elements to be recombined. Accordingly, recombination is usually "assumed" to be equivalent to innovation in the literature, and one of the sources of recombination is taken to be variety.

However, it is important to note that recombination capabilities are largely firm-specific (Kogut and Zander, 1996) and embedded in their internal routines in storing, retrieving and processing knowledge, in a way independent from the existing *level* of technological diversification. In other words, firms differ from each other in the level and extent to which they can make use of diverse technological domains. In our first hypothesis, we aim to test whether the assumed relationship between recombination and innovation really holds.

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

It is also possible to argue that there is a limit to the positive effect of recombination on innovation. In fact, this positive effect will depend largely on the *rate of change* of variety in the firm (Vanden Bergh, 2008; Garcia Vega, 2006). The rate at which the technical variety in a firm changes is slow, because of the established and routinized learning processes which may inhibit the rate at which firms can absorb new knowledge in new technical domains. Thus further possibilities of innovative output, using the slowly changing current technical domains will be exhausted even tough the firm has high recombination capabilities. In other words, for a given (or slowly changing) level of variety, the recombinative capabilities will no longer yield higher innovative capabilities. Therefore we propose that,

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

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

Recent studies show that in various industrial contexts, the portfolio of firms' alliance partners influence the performance of the focal firm. An important mechanism through which alliance portfolio influences the performance of a firm is through organizational learning (Phelps 2010; Lavie, Kang, Rosenkopf, 2011) and capability transfer (Mowery et al., 1998), 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 it, exploration in 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 process, 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, and also internal. Whether firms treat these to be substitutes or complements has been a matter of debate in the literature (Lavie, Kang, Rosenkopf, 2011; Lavie and Tushman, 2010). A growing body of literature investigates exploratory and exploitative alliances in a firm's alliance portfolio, and its effect on firm performance.

A firm's alliance portfolio can be constructed in relation to diversity of partners (Jiang, 2010; Lin Yang Arya, 2010; Phelps, 2010), foreignness of alliance partners (Lavie and Miller, 2008), exploration vs. exploitation alliances (Lavie and Rosenkopf, 2006; Yamanawa, 2010) technological distance/overlap between the partners (Mowery, Oxley and Silverman,1998; Vanhaverbeke et al, 2009). The results of this literature reveal that partner diversity is better for explorative innovation (Phelps, 2010; Lavie and Rosenkopf, 2006) 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. Yamanawa (2010) concludes that the performance effects of portfolios depend largely on the industry and the firm characteristics.

Fairly increasing number of studies detect a curvilinear relation between the distance 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 distance diminishes as firms collaborate with each other (Mowery et al., 1998). In addition, the likelihood of an alliance between two firms is higher when their distance is at an intermediate level (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 production of knowledge? Based on the 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. We propose that:

Hypothesis 3: There exists an inverted-u relation between the innovative capabilities of a firm, and the average technological overlap 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 Distance in Alliances

While strategic alliances are usually considered a source of variety (Rosenkopf and Almeida, 2003), and that exploratory search processes are associated with the ability of the firm to maintain variety ((March, 1991; McGrath, 2001), whether the firm can absorb the new knowledge accessed through exploratory search and build upon it through recombining with the existing knowledge domains in the organization 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). Previous studies have looked at how absorptive capacity and the network position of the firm influence jointly the innovative capabilities. For example, firms who have higher absorptive capabilities can make better use of central positions in networks (Tsai, 2001), and they can deal better with heterogeneous information (Shipilov 2009). Based on a sample of pharmaceutical firms, Hess and Rothaermel (2011) found evidence of the complementarity between internal knowledge (measured with scientific star) and strategic alliance combinations that are different. On the other hand, once these internal and external resources are similar as they apply in the same value chain, they result to be redundant and they are substitute.

Exploratory search processes are highly risky, but they can have higher returns than deepening through exploitation. Notwithstanding such positive and negative aspects of exploratory alliances, research shows that firms search narrowly within their existing technological domains (Helfat, 1994) which are referred to as exploitation (Stuart and Podolny, 1996). However, for increased innovative capabilities, firms need to explore new knowledge as well, 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 (Leonard Barton; Cohen and Levinthal, 1991). Expressed in terms of technological distances, exploitative alliances are usually associated with ones in which technological profiles of firms are close.

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 efficient 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 (Miller, Fern, Cardinal, 2007; Galunic and Rodan).

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, which is a major aspect of innovation, requires both a profound understanding of the relevant domain, and the 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 variety and its operationalization, exploitative alliances (which are usually with firms whi 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). Therefore, 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 innovative performance.

3. Method and Data

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 which are essentially big firms. 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 database, bnet.com website and firms' website. Thus our sample includes only firms that have a least one cooperation (alliance, research cooperation) registered in the CATI database. 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, we briefly details the variables contained in our dataset before presenting descriptive statistics. 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.

3.1.1 Patent information

The primary goal of this paper is to analyze how both technological proximity with partners and their internal knowledge exploitation affect the innovative competencies of ICT firms. Thus, 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 granted patents by the USPTO and we also collect granted patents of the firms involved in the strategic alliances with the ego firm[1]. Patents were searched by hand using the firm name, along with familiar abbreviations, and evident variations in spelling of firms' names. This detailed research permits to include all patents granted. A patent document is a rich source of information for our purposes. 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. A patent document is assigned a main code, as well as secondary ones. IPC classes represent an interesting source of information as they show the technology field in which the patent belongs to. In our study, the main and secondary IPC codes of patents are used to derive measures of recombinative capabilities. Although patents are usually considered to be a good source of measuring innovation input, patent data have some limitations (Griliches, 1990; Silverman, 1999). There is part of technical knowledge which might remain unpatented either because it is not patentable or because a firm may decide not to patent to keep in secrecy. Our primary interest is to analyze the influence of technological proximity with partners and the internal knowledge exploitation both measured with granted patents of the firms. Thus, we consider as *dependent variable*

[1] 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.

the number of patent granted by each firms and we use IPC code patent to compute the technology proximity and the recombination index.

3.1.2 Recombinative Capability

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). [2] 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:

$$R_{it} = \frac{\sum_j b_{ij}}{P_{it}}$$

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 as it permits to consider the reverse causality.

[2] 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) .

3.1.3. Technological Distance 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 close 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 firm measures the breadth of the knowledge as revealed by the range of different technology fields that a firm patents in. 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 firm in our database between 1995 and 2003, we collected the technology based cooperative agreements that the firm was involved in. This data was collected from the MERIT CATI (Cooperative Agreements and Technology Indicators) relational database, which 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 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. For this purpose, we converted all the IPC codes of patents in the sample into one of 30 main technology fields (Schmoch, 2008). In this way we included a total of 2980 alliances, for a total of 1200 firms. We use the cosine index 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 closer they are in the technology space. Cosine index between firms *i* and *j* is calculated in he following way:

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

where, a_{ik} refers to the proportion of technology field *k* in all the patents taken by firm *i* in a given year. Obviously, $\cos_{ii}$ =1, and if there is no common technology field between the patent portfolios of two firms, $\cos_{ij}$=0. Other cases fall in between the two extremes. 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 distance with its alliance partners. 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 sound measure of the firms' partner selection strategy for a given year. The Interaction effect is computed using Cronbach method as it is the results between Recombination index multiplied by Technological Distance.

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. 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 rigidities which hamper 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.

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 characteristics such as patenting behaviour of software firms.

3.2 Descriptive statistics

Before advancing to our estimation of the innovative production in Section 4, we briefly present some descriptive statistics of the sample. In total, our sample contains 71 firms that are recorded among those that invest more in R&D expenditure and they have at least one strategic alliance agreements recorded in the CATI database. The smallest firm has 600 employees and the largest 668000 employees. Table 1 presents the descriptive statistics of all variables. Table 2 reports the broken down figures according to the different industrial sectors. The majority of the firms presented in the sample are established in USA 50% of the firms, 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
Recombincation $_{it-1}$	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
Recombincation sq $_{it-1}$	Recombination in square	.0025	.0060	0	.076
Technological distance $_{it-1}$	Technological distance 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
Technological distance in sq $_{it-1}$	Technological distance in square	.3868	.2633	0	.986
Recom $_{it-1}$ *TechDist $_{it-1}$	Interaction effect Recombination index multiplied by Technological Distance-Cronbach	.0203	.0185	0	.1284
Log $R\&D_{it-1}$	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
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
EU	Dummy variable sets to one if the firm is based in EU	.1549	.3621	0	1
Other	Dummy variable set to one if the firm is based in other country	.0704	.2561	0	1

Table 2. Detailed data on firms by 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; Trasmission and processing of data or communications (NAICS 511-8)	8	Ericsson, I2 Technologies, Oracle
Professional, Scientific, and Technical Services Other NAICS	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 and GEE population average model shows that the standard errors reflecting efficiency gain due to better model identification.

$$Patent_{it} = \alpha + \mathrm{Re}\,combination_{it-1} + Tech\,dis\tan ce_{it-1} + \mathrm{Re}\,combination_{it} * Techdis\tan ce_{it} + RD_{it-1} + \delta_i + \varepsilon_{it}$$

with $Patent_{it}$ being the number of patent of the firm *i* in time t; δ_i are set of *i*th firm chareteristics which measures the firm-specific heterogeneity and ε_{it} represents the error which is assumed to satisfy the usual regression model conditions. The Hausman test confirms the use of random effect.

Table 3. Results of the panel estimation

	(1)	(2)	(3)
	Poisson RE	Poisson RE	Poisson RE
Recombincation $_{it-1}$	2.366*	8.177***	8.148***
	(1.282)	(1.695)	(1.695)
Recombincation sq $_{it-1}$	-64.869***	-111.955***	-111.994***
	(7.294)	(10.753)	(10.757)
Technological distance $_{it-1}$	1.866***	1.666***	1.668***
	(0.104)	(0.111)	(0.111)
Technological distance in sq $_{it-1}$	-1.716***	-1.442***	-1.443***
	(0.080)	(0.084)	(0.084)
Recombincation $_{it-1}$ *Technological distance $_{it-1}$	8.150***	5.318***	5.321***
	(1.610)	(1.955)	(1.955)
Log $R\&D_{it-1}$		-0.039**	-0.038**
		(0.015)	0.039**
Age			(0.017)
			(0.014)
Agesq			0.001
			(0.001)
NAICS 334			-0.507
			(0.593)
NAICS 541			0.295
			(0.899)
NAICS 32;33			-0.953
			(0.703)
NAICS 511-8			0.028
			(0.759)
USA			-0.091
			(0.713)
JAPAN			0.533
			(0.734)
OTHER			1.354
			(0.928)
_cons	4.452***	4.680***	0.504***
	(0.168)	(0.215)	(0.145)
N	295	249	249
Wald chi2 Prob > chi2 = 0.0000	9060.96	8649.68	8673.75

4. RESULTS

Table 3 presents the results for the estimation of the production of knowledge measured with the firms' number of patents. To check the robustness of our estimation, we perform different estimations[3].

[3] We also estimate the fixed effect model and the results are confirmed.

Regression 1 and Regression 2 estimate the equation using time-varying variables. Finally, Regression 3 includes all time-varying variables. All estimations include time dummies.

The results corroborate the Hypothesis 1, confirming that innovative competencies are positively influenced by recombinative capabilities. 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, recombination of internal knowledge positively affects the production of innovative competencies as firms can fully exploit their internal knowledge which allow to firm to maintain variety. However, the recombination of internal competencies has positive effect on innovative competencies upon a certain point which shows that excessive recombination can create inertia in the innovative activities of the firms.

Similarly, the results confirm the Hypothesis 2 that there is an inverted u-relation between the innovative potential of a firm, and the average technological distance between itself and its alliance partners. The results confirm the Hypothesis 3 that innovation performance is a parabolic, inverted-U shaped function of technological distance measure; the linear term of recombinative measure has a significant and positive effect and the quadratic term a significant negative effect. This result has previously been confirmed in different studies in the context of explorative innovation (Nooteboom, 2007). Rather than assuming that differences in term of technological knowledge can increase the complexity of firms' activities, one should also recognize the positive potential of such differences.

The empirical literature has confirmed this results of positive effect of collaboration with other firm – linear effect of the technological distance variable (Rosenkopf and Nerkar, 2001; Rosenkopf and Almeida, 2003; Ahuja and Katila, 2004; Nooteboom et al, 2007). The interaction effect between technological similarity (between the firm and its partners) and firms' recombinative capabilities positively influence the production of knowledge 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.

$R\&D_{it-1}$ expenditures in time t-1 which measures the innovative input of the firms and the size of the firms as larger firms spends more in R&D expenditure. 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. Regression 4 includes all control variables. Additionally, we introduced annual dummy variables 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.

5. Concluding Remarks

In this paper, we analyse how internal and external factors complement the ability of firms to combine diverse knowledge in order to create innovative competencies. The aim of this paper is to advance our understanding how recombination of knowledge and technological proximity with other firms can influence the production of innovative capabilities as measured by patents.

In particular, two mechanisms are focused on as far as they have implications for innovation. Firstly, we test the effect of recombinative capabilities of firms on their innovative capabilities. We take recombinative capability as one of the essential determinants of innovative capabilities. This is in accordance with the Schumpeterian notion of resource combinations, which 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 depends on the firms abilities to create and maintain variety inside the firm. Several mechanisms exist for this, one of which is strategic alliances. However, accessing new knowledge is not sufficient for innovation; 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. In this paper, we find that, firms who have higher recombinative capabilities have better innovative performance. Our results reveal that, there is a significant positive influence of recombinative capabilities on innovative potential of the firm. In other words, we show that firms with higher recombinative capabilities can better make use of variety and thus increase their innovative potential. 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).

It should be noted that, we measured innovative performance by the number of patents. Because patents do not measure the commercial success of innovations, we should be careful in interpreting these results. In other words, our results are concerned with the creation of new knowledge (which we take to be innovative capability, as is usually done in the literature) , as determined by patents.

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 distance of the firm with its partners. We detect a curvilinear relation between the average distance between the firm and 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. Our work is different from the previous ones in several aspects. Firstly, we take the unit of analysis as the firm, rather than a dyadic relationship. Secondly, we look at the effect of the average technological distance of the firm with its partners, rather than diversity of its portfolio. In addition, we do not distinguish between explorative and exploitative innovations, but rather investigate how the production of knowledge of the firm is influenced by the average distance with its partners. Finally, we look at the effect of recombination together with average technological distance.

In this paper, we investigate how the external partners of the firm and the firm's internal research capabilities shape jointly the production of knowledge of the firm. The underlying motive in the paper is that, firms with higher recombinative capabilities can better make use of their external relations in the innovation process. In a regression model, we jointly included both recombinative capabilities of firms and their average technological overlap with their partners. Our results reveal that both recombinative capabilities and the firms' technological overlap with its partners are significant mechanisms which influence the innovative capabilities of firms in the ICT sector.

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