Recombination of Diverse Technologies in a Firm: Do Networks Matter?

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Abstract The aim of this paper is to highlight the determinants of firms ability to recombine diverse knowledge types within their organization. For this purpose, the paper argues that the balance between exploration and exploitation is critical. In particular, two problems can inhibit firms from effectively recombining diverse knowledge. Firstly, the risk of excessive technological deepening can limit the range of distant knowledge fields that the firm choses to access in its exploration activities. In this case the firm is more favourable to knowledge which is closer to its competences. Such selectivity can be critical if the firm adopts open innovation strategies to access knowledge from outside. Secondly, even if the firm diversifies technologically and has access to distant knowledge, it may not be able to effectively combine these diverse knowledge types within its boundaries. Internal networks may have a critical role in this process. The effect of technological deepening and inventor networks on recombinative capabilities are analysed through a regression analysis performed on patents taken by ICT firms. Some preliminary results reveal that the density of networks within the firm is a critical complement to open innovation strategies. Firms with dense inventor networks have higher recombination capabilities. At the same time, excessive technological deepening has a negative effect on recombinative capability.

1 Introduction

The history of technological change is full of examples in which a disruptive innovation, which marks a radical change in the dominating technical regime is the result of a combination of previously existing but disparate knowledge in novel ways (Bassala, 1988). Most of the times, the ability to combine diverse knowledge is seldom attributable to one star inventor; rather, it is the result of a network of ideas, objects and people, within or outside an organizational context (Hargadon and Sutton, 1997). Because of the critical role of both internal and external knowledge in innovation, the firm should be seen not only as a network within itself, but also it should be seen as a node in a broader network of ideas, people and artefacts. Open innovation emphasizes the importance of external networks in this process (Chesbrough, 2003). But the question is whether or not open strategies are sufficient by themselves to increase the innovative performance of firms? For this purpose, we investigate the internal factors which complement open strategies, namely the ability of firms to combine diverse knowledge they acquire from outside within their boundaries.

The aim of this paper is to advance our understanding of the factors which contribute to the combinative capabilities of firms. The central premise of the paper is that, the ability of the firm to combine diverse ideas rests in its ability to effectively balance exploration and exploitation dimensions of organizational learning. We draw upon the organizational learning literature to highlight the problems that firms might face in this process. The first problem is that, firms may filter out external knowledge which is distant from their existing competences. This reduces the range of external knowledge types that firms access outside their boundaries. Secondly, even if they do absorb a wide range of technologies and knowledge outside their boundaries, firms may not be able to successfully leverage an internal communication mechanism to combine diverse sources of knowledge inside. We argue that in both cases, the ability of the firm to successfully recombine knowledge is inhibited. To test these claims, we perform a regression analysis using patents taken by ICT firms between 2000 and 2005 collected by the European Patent Office (EPO).

The paper is organized as follows. In the first section, we present the background literature, and present our hypotheses. In the second section, we explain the data and measures used in regressions. In the third section, we analyse some preliminary regression results.

2 Background

Recently, the concept of open innovation has advanced our understanding of how an open strategy can help firms to acquire and build upon the knowledge that is beyond their boundaries. Open innovation broadly refers to the creation, development and maintenance of channels through which firms access external sources of knowledge and reduce the costs of access to their own knowledge bases (Chesbrough, 2003). Open innovation emphasizes the "collective" nature of the innovation process, which has been the central premise of the innovation literature since 1980s (Nelson and Winter, 1982; Allen, 1983).

In general it is now accepted that extending beyond firm borders can be advantageous in several ways; to reduce products.introduction time to the market, reduce the risks of innovation and share the costs of R&D (Hamel et al., 1989; Hagedoorn, 1993); organizational learning (Powell et al., 1996) and network effects (Garud and Kumaraswamy, 1993), among other benefits. An important effect of open innovation is its potential to deepen the knowledge of firms in terms of know-how. Through open innovation firms access the knowledge bases of other firms whereby they explore novelties lying outside their boundaries and also exploit their existing knowledge (March, 1991; Rosenberg 1994).

The organizational learning literature traditionally focuses on the trade-off between firms investment in exploration and exploitation. The former refers to experimentation with new alternatives, whereas the latter refers to the "exercise of refinement and extension of existing competencies, technologies and paradigms" (March, 1991: 85). It is now accepted that these two dimensions of organizational learning are not substitutes but complements with each other (Tushman and O.Reilly, 1997; Lavie and Rosenkopf, 2006)□□In other words, for higher innovative performance, firms should have the capability for, and invest in, both exploring and exploiting. The innovative performance does not only depend on the range of different knowledge that the firm acquires from outside, but also on its ability to absorb these (Cohen and Levinthal, 1991) and build upon them through recombining the diverse knowledge in the organization. Hence, firms should be able to capture the value of the external knowledge and integrate it within the firm, 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, 1991)□□

The central premise of this paper is that, the balance between exploration and exploitation is a critical issue, which may determine the firms.ability to recombine knowledge. There are few problems that firms face in this process of joint exploration and exploitation. Firstly, firms can be biased towards knowledge which is closer to their core competences. When this is the case, the firm can act as a .filtering mechanism, and be closed to distant knowledge categories. This can mostly be the case when core competences turn into core rigidities (Barton, 1992)□□In this case, effective exploration can be inhibited, limiting the choices of the firm to technologies which are closer to its competences. One of the ways in which firms cope with this risk is to diversify technologically (Grandstrand et al., 1997).

Technological diversification refers to the case where the firm knows more than it makes. In fact, one of the reasons behind diversification is to be able to comprehend diverse technologies developed beyond firm boundaries. But technological diversification does not imply that diverse knowledge inside the firm is effectively shared, combined and could be put into new products. For exam- ple, when innovative units (people, teams or departments) inside the firm become too specialized in their respective areas, it might be more difficult to establish communication links between disparate units. In this case, as long as the knowledge of these groups are not combined in novel ways, maintaining and investing in a wide variety of knowledge types can be a costly process. To our knowledge there is no empirical study to test this claim. But Kogut and Zander (1992) effectively argue that the more specialization is there within the firm the more costly is communication within the firm (Kogut and Zander, 1992). In other words, specialization reduces the ability with which people can form a common language, and transfer highly tacit knowledge that they possess. In most cases, creative knowledge within the organization is shared and created by means of informal communication mechanisms and in joint problem solving activities, rather than through formal mechanisms like management information systems. A range of studies analyse the effect of such internal communication mechanisms, mostly focusing on the relation between structure of networks and knowledge .ows. For example, Hargadon and Sutton (1997) emphasize the role of technology brokers. Hansen (2001) stresses the importance of knowledge relatedness and costs of communication. Based on this discussion, the second problem firms face in joint exploration and exploitation is that, even if firms have access to a wide range of distant knowledge types, and successfully acquire them, they may not be able to establish an internal network which ideally functions so as to merge the knowledge of diverse innovative units.

Based on this discussion, the aim of this paper is to advance our understanding of the determinants of recombinative capabilities of firms. We define recombinative capability as the capability of the firm to combine existing, but possibly distant knowledge types in novel ways, within the organization. For this purpose, we carry out a regression analysis based on the patents applied by ICT firms between 2000-2005. In particular, we look into the effects of two variables on recombinative capability. The first is the technological deepening of the firm, which refers to the extent to which the firm is specialized on a certain technology. Firms that are exceedingly deep in terms of their core competences maybe highly vulnerable to the negative effects of core rigidities, as explained above. In this case, their ability to be open to a wide range of external knowledge can be limited, and they can become more biased towards technologies which are closer to their knowledge base. Based on this discussion, we hypothesize that:

Hypothesis 1: Firms which are less technologcally diversified have a lower capa- bility to recombine di¤erent technology fields.

Secondly, we investigate the effect of internal communication mechanisms within the firm. For this purpose, we investigate how inventor networks within the firm influence the combinative capability of the firm. It is possible to expect that, firms whose inventors have dense links with each other have more capabilities to combine diverse ideas within the firm. To measure internal communication mechanisms, we use inventor network density as an independent variable in the regressions. We hypothesize that:

Hypothesis 2: Firms with dense inventor networks are better in recombining dif- ferent technology fields. In the next section we explain the data and the measures employed as well as the regression model.

3 Data

A patent document is a rich source of information, since it contains information on the relevant technology codes related with the subject matter of the patent, which is given by the 8-digit IPC code. A patent document is assigned a main IPC code, as well as secondary codes. In our study, these IPC codes are used to derive measures of recombinative capability and technological deepening. In the study, a total of 160 firms, who have majority of their patents in the ICT sector are included. A total of 360,000 patents taken by these firms between 2000-2005 are included in the study. Firms were selected based on the following process. Firstly, the Eurostat (2008) patent classification, which lists the IPC codes in the ICT sector, is used to collect all the patents applied between 2000 and 2005. In this way, we came up with a total of 317 firms, having at least a total of 350 patents between the mentioned years. In the next stage, we collected all the patents taken by these firms, and not just in the ICT field. Among this list we selected firms whose patents are composed of at least 50 % in ICT fields. Form this list, firms whose total number of patents are above 8000 are deleted, because they were outliers in terms of the size of their patent pool. In this way, we are left with a total of 160 firms who operate mainly in the ICT sector. The IPC codes of all the patents in the sample are then converted into a specific technology .field, based on the correspondance prepared by Fraunhofer Gessellschaft-ISI (Karlsrube), Institut National de la Propriete Industrielle (INPI-Paris) and Observatoire des Sciences et des Techniques (OST, Paris) and it is mainly composed of an allocation of IPC codes into technology fields (Schmoch, 2008). Below we provide the descriptions of combinative capability, network density and technological deepening as they are used in the study. Some descriptive statistics concerning the regressions can be found in the Appendix.

3.1 Measuring Combinative Capability

The aim of the paper is to distinguish the factors which influence the combinative capability of firms. Therefore, we take combinative capability as the dependent variable in the regressions. To measure the combinative capability of a firm, we look at the number of different technology fields which appear on a single patent document taken by the firm. This can be called as the breadth of a patent document. The breadth of the patent measures the width of different technology fields that the IPC list of a patent covers. 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 each IPC code in the data set to the corresponding technology .field, as explained in the previous section. For each patent, we counted how many times a particular technology .field is repeated. The more the different types of technology fields that a given patent extends to, the wider its knowledge base taken to be. Having recorded the frequency of each technology .eld for all patents of a firm, the combinative capability of the firm i in a particular year was calculated in the following way:

$$COMB_{it} = \frac{\sum_{j=1}^{N_{it}} b_{ij}}{N_{it}}$$

where b_{ij} is the breadth of firm i's patent j and N_{it} is the total number of patents of firm i in period t. Therefore, combinative capability is measured by the average of breadth of a patent document.

Breadth of a patent measures the range of diverse technology .elds that a patent covers. For this purpose, we use the Blau index (1977) which is traditionally used to measure diversity in a population in sociological studies. It is given by:

$$b_{ij} = 1 - \sum_{k=1}^{k=30} a_{ik}^{2}$$

where □□□□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. When a firm can combine a diverse range of technology fields in a patent, we assume that its capability to combine diverse fields is higher. Therefore firms with smaller values of blau index has more combinative capabilities, than firms with higher values of the Blau index.

3.2 Measuring Diversification

Diversification refers to the extent to which firm takes patents in different technology fields. Here we do not look at breadth of one patent document, but rather we look at the overall patent pool, and measure the extent to which the firm has a diverse portfolio of patents. To give an example, a diversified firm will have a patent portfolio covering a range of diverse technology fields. But this does not mean that the firm can combine these fields in a single patent. We measure technological diversification of firm i in period t in the following way:

$$DIV_{it} = 1 - \sum_{k=1}^{k=30} q_{ik}^2$$

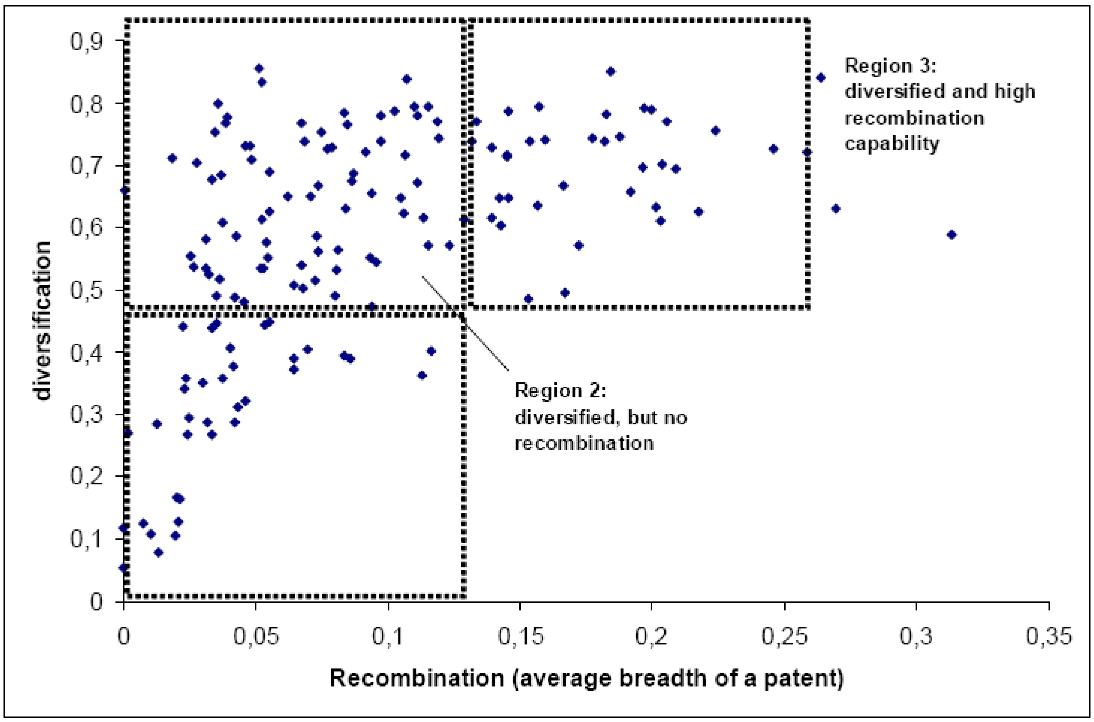
where □□□is the technological diversification of firm i in period t, and □□□is the proportion of technology .field k in the overall patents taken by the firm in period t.

When firms are too much specialized on a particular technology field, the firms core competence can act as a "core rigidity" (Barton, 1992). When this is the case, the firms ability to acquire, absorb new knowledge from outside, and to combine it with its own competences can be more difficult. In other words, the firm can act as a filter in accessing distant knowledge .fields, being more biased towards knowledge that is not too distant from its core competence. In this case, the firm can loose its .exibility to both explore novel .elds, and also to exploit these .fields through combining them with its existing knowledge base. Such rigidities are oppositely correlated with technological diversification. Therefore we take the reciprocal of technological diversification measure D□□□to measure the extent of technological deepening of the firm. Therefore we hypothesize that, technological deepening can have a negative impact on the combinative capabilities of the firm. Firms with a smaller values of the index are technologically deeper.

As an alternative measure of diversification, we use a direct count of different IPC codes that the firm uses in its patent pool. This measure appears as DIVD in the regressions in the next section.

3.3 Diversification and Recombination

Obviously, the two measures are not totally independent, but only partially so. In other words, a firm which is technologically deep means that it does not have a wide patent portfolio composed of different fields. Obviously in this case, it cannot have patents which combine diverse fields. However, the opposite is not true. A firm which is technologically diversified, may or maynot have the ability to combine them in a patent. Figure 1 shows the ICT firms scattered in the diversification - recombination space. Here we distinguish between 3 regions.



The firms in the first region are not technologically diversifed, but rather they are specialized in certain technology fields. The firms in the second region are highly diversified but individual patents are specialized in certain .fields. The firms in the third region have both high D□□□and high □□□□This means that these firms are not only technologically diversified, but they can also combine these diverse technology fields in the individual patents that they take. In our sample, the firms with high combinative capabilities exist in the third region.\

3.4 Measuring Network Density}

One of the determinants of recombinative capability can be the internal communication mechanisms within the firm. In the regression, one of the independent variables that we use to measure the effect on combinative capability is the density of inventor networks in the firm. For this purpose, we measure the inventor network densities for all firms in the sample, for 2000-2002 and 2003-2005. Because we are concerned with internal knowledge flow mechanisms, we do not take into account links with inventorsfrom outside firms. Rather, we form a network of inventors within the firm, by assigning a value of 1 if two inventors names appear in the same patent document, and if the two inventors are from the same firm. Network density measures the intensity of connections, and is calculated in the following way:

$$NetD_i = \frac{\sum_{i=1}^{N} \sum_{j=1}^{N} x_{ij}}{N(N-1)}$$

where $x_{ij} = 1$ if there is an edge between i and j and is 0 otherwise and N is the total number of nodes.

3.5 Control Variables

Other variables can affect the recombination of the internal knowledge, for this reason we include different control variables. The additional control variables have been collected in the database MarketLine and in the website of the firms. We include dummy variables indicating the company headquarter which allow to measure the difference among the different continents. The reference variable in the regression is the dummy variable Korea. Additionally, we add two organisational variables. Firstly, we measure the age of the firms (we put in square to look for the overdispersion). We expect that older firms have more e¤ective internal knowledge exchanges. Secondly, we include the number of employees to measure the size of the firms. Here, smaller firms can have more willingness to exchange internal information. Larger firms are expected to have larger

.nancial means in respect to smaller firms. However, large firms can have some rigidities which hamper the explorative knowledge activities (Gilsing et al., 2008).

4 Preliminary Results

The results given in this section are based on a series of preliminary regressions that we performed. As our independent variables is a continous major we use a simple regression to estimate our equation. We use a random effect model as we compute the Breusch and Pagan Lagrangian multiplier test for random e¤ects which reject the null hypothesis of the individual effects. For our regression, we use the software Stata 9.1 which has already implemented the regression function for the panel data. Figure 2 shows some of the preliminary regression results. The results of the regression shows that there is a geographical patterns in the the recombination of diverse activities within the firms. Japanese firms perform better recombination of diverse activities accompanied by the European firms. According our results, we can assert that firms with dense inventor networks are better in recombining different technology .elds in the first period between 2000 to 2002 as the number of the patents is higher. Additionally, index measuring patents diversification positively influence the recombination of knowledge of the firms corroborating our hypothesis.

COMB	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
DIV	0,1605929***	0,1461319***	0,1419905***				
	-11,57	10	8,64				
DIVD				0,1753885***	0,1597534***	0,1857265***	0,1568187***
				12,57	10,68	9,28	9,34
NetD00-03	0,2889614	0,7718304*	0,7656085*	0,4063766	0,8109987*	0,9559921*	0,8098655*
	0,76	1,81	1,73	1,08	1,92	1,85	1,85
NetD03-05	0,4353874*	-0,1398456	-0,0194042	0,5591934**	-0,0131531	-0,1771767	0,1246667
	1,9	-0,45	-0,05	2,45	-0,04	-0,32	0,35
Const	-0,0018155	-0,0486069**	-0,0544727**	-0,0155493	-0,0561467**	-0,0998361	-0,0617014**
	-0,19	-2,69	-2,25	-1,54	-3,11	-1,45	-2,54
eu		0,0492813**	0,0526415*		0,0428305*	0,0302058	0,0454256*
		2,43	2,12		2,12	0,58	1,83
usa		0,0382752*	0,0341347		0,0325879*	0,0289414	0,0275279
		2,07	1,49		1,77	0,56	1,2
taiwan		0,0467194*	0,0409443		0,043995*	0,0579233	0,0381817
		2	1,49		1,9	1,08	1,4
japan		0,0918496***	0,0879512**		0,0864614***	0,0817478	0,0818914**
		5,01	3,71		4,74	1,58	3,45
othercountry		0,0446085	0,0470962		0,0427849	0,0512833	0,0448862
		1,44	1,36		1,39	0,88	1,3
yearfounded			0,0004561			0,0001788	0,0004525
			0,8			0,29	0,79
yearfounde~q			-3,64E-06			-9,05E-07	-3,67E-06
			-0,82			-0,2	-0,83
lnemployee						0,0018898	
						0,44	
R^2 *within*	0,0945	0,1068	0,0976	0,1163	0,1213	0,1568	0,1158
between	0,2899	0,4446	0,407	0,3024	0,4525	0,4572	0,4089
overall	0,2298	0,3467	0,3322	0,2447	0,3559	0,3699	0,3394
N	884	783	648	884	783	451	648

5 Conclusion and discussion

It is important to mention that the results presented in this version of the paper is largely preliminary. Nevertheless, they show that internal networks are critical if firms want to benefit from the knowledge they acquire from outside. In particular, recombination of diverse knowledge is an important dimension of innovation, and this article attempts to study the determinants of firms ability to recombine diverse knowledge types within their organization in an open innovation setting. To create new knowledge firms should be able to recombine internal and external knowledge. We use patent panel data collected by the EPO between 2000 and 2005 in ICT sector to study to what extent firms have incentives to recombine diverse knowledge. The recombination activity is majored by the diversity index which computes the diversity of patents withint the firms. Then, we add measures of network links within the firms for two periods from 2000 to 2002 and from 2003- to 2005. Other variables can in.u- ence the recombination activities of the firms hence we include some control variables such as geographical dummies capturing the headquarter localisation, log of employee number and the age of the firms since has been founded. Some limitations should 12 13 be underlined. Particular attention should be given to other organisation variables, hence we need to control for the R&D expenditures, which we will incorporate in the future version of the paper.

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