Knowledge flows, firms' competencies, and patent citations: an analysis of the trajectory of IBM

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Abstract

In a knowledge economy, the creation, distribution and use of knowledge become decisive factors to reinforce firms' competitiveness. At the firm level, the process of innovation involves, fundamentally, the creation of new knowledge, which implies the integration and recombination of existing knowledge that may come from different sources and locations. The analytical difficulties to deal with this subject generate a literature that tries to quantify and analyze knowledge flows between economic agents using patent citations. Those citations may provide clues for intra and inter-firms knowledge flows. The paper analyses information about patents granted by IBM in the USPTO, which is used to map knowledge flows and to correlate these flows with the evolution of IBM competencies and growth strategies.

Key-words: Patent Citations; Knowledge flows; Firms Competences, IBM Competences; IBM Strategy

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Introduction

In a knowledge economy, the creation, distribution and use of knowledge become decisive factors to reinforce firms' competitiveness. At the firm level, the process of innovation involves, fundamentally, the creation of new knowledge, which implies, to a large extent, the integration and recombination of existing knowledge that may come from different sources and locations. Some knowledge may reside within the boundaries of the innovating company, while other bits may come from other companies, in the same industry or in related fields. However, the characteristics of knowledge flows remain unclear in most cases. The analytical difficulties to deal with this subject generate a specific type of literature that tries to identify, analyze and quantify the process of knowledge flows between economic agents in a detailed way. Patent citations have been used as proxy for knowledge flows at least since the pioneer work of Jaffe and Trajtenberg (2002). After a previous research on scientific papers cited in patents (Ribeiro et al, 2010), this article focuses on patent cited by other patents. The hypothesis here is that those citations may provide clues for intra and inter-firms knowledge flows.

Our investigation is based on information about patents granted by IBM in the USPTO in 1974, 1982, 1990, 1998 and 2006. Specifically, the database comprises two aspects: i) the distribution of firms cited in IBM's patents and the distribution of firms that cited IBM in their patents; ii) the number of citations in IBM patents distributed by different technological domains. This information will be used to map knowledge flows and to correlate these flows with the evolution of firms' competences and with firms' growth strategies. The paper is organized as follows. The second section presents the theoretical and analytical framework regarding the use of patent citations to map knowledge flows and to discuss the evolution of firms' competences. The third section presents a synthetic overview of the recent evolution of competences, innovative performance, and IBM's growth strategies. The fourth section use information about patent citations to track and discuss the evolution of IBM's competences and knowledge flows. A conclusive section summarizes some general trends captured from the data and some possible outcomes to be explored in other analyzes.

2 - Theoretical and analytical framework

2.1 - Knowledge spillovers and firms' competences

In the context of a knowledge economy, economic agents tend to be connected not only through input-output relations but also through knowledge flows. At the firm level, the process of innovation involves, fundamentally, the creation of new knowledge, which implies, to a large extent, the integration and recombination of already existing knowledge that may come from different sources and locations. Some knowledge may reside within the boundaries of the innovating company, while other bits of knowledge come from other companies, in the same industry or in related fields. Yet, another useful knowledge flow comes from long-term relationships with users and suppliers, as well as from universities and S&T infrastructure.

This aspect has induced the emergence of a literature that tries to identify, analyze and quantify knowledge flows between economic agents in a detailed way. In this context, a relevant aspect comprises how the knowledge is diffused from one agent to another. This process is not easy to conceptualize and even harder to measure. In this debate, a topic that has received a specific attention comprises the analyses of knowledge spillovers. According to the definition given by De Bondt (1996), a ‘knowledge spillover’ is specified as an ‘involuntary leakage or voluntary exchange’ of technological knowledge. Another definition, proposed by Nieuwenhuijsen and van Stel (2002), describes knowledge spillovers as the situation, in which one economic agent benefits from innovative efforts of another economic agent without any tangible remuneration. We can also distinguish between intra and inter-sectoral spillovers. Intra-sectoral spillovers occur when the knowledge resultant from innovative efforts performed by firms in a particular sector might be partially accessed by other firms in the same sector. On the other hand, inter-sectoral technology spillovers are established through a process of technological integration of innovations that intersects many technological classes, which may result in shifts of the already established technological trajectories. Knowledge spillovers should also be classified as vertical or horizontal (Bernstein and Nadiri, 1988). Horizontal spillovers occur between competitors, and vertical spillovers happen between firms of different fields.

It is possible to articulate these processes with an evolutionary theory of the firm. In this perspective, firms' competences comprise the domain of specific knowledge bases, articulated to the practical experience of the production in order to consolidate their capacity to perform certain activities. Competencies are embedded in organizational processes or routines that include processes of coordination, learning and transformation. Knowledge is conceived as a cognitive ability that is reflected on the firm’s capacity to interpret and apply information - defined as a set of data, formatted and structured, related to the products, processes and markets (Foray and Lundvall, 1996) - in a specific context (Arora, Gambardella, 1994, Dosi, Nelson, 2010 and Foray, 2007). Skills and competencies become critical determinants of firm's competitiveness (Dosi and Teece, 1998), with their developing being articulated to different learning mechanisms, which occurs in a specific and cumulative way. Firm-specific technological competencies help to explain why firms are different, how they change over time, and whether or not they are capable of remaining competitive.

According to evidences collected empirically by Patel and Pavitt (1995) the largest firms have the following characteristics in terms of technological competencies: 1) they are typically multi-field, and are becoming more so over time, with competencies going beyond their product range, in technical fields outside their 'distinctive core'; 2) they are highly stable and differentiated, with both the technology profile and the directions of localized search being strongly influenced by firms' principal products; 3) the rate of search is influenced by both the firm's principal products, and the conditions in its home country. These findings confirm the importance of complexity and path dependency in the accumulation of firm-specific technological competencies, showing that managers are heavily constrained in the directions of their technological search. Technological strategies in large firms are rarely 'focused', since the products they develop require the integration of knowledge from a wide range of technological fields. In this context, distinctive core' technological competencies are not enough, since large companies must also be competent coordinating technological change and accessing multiple relevant knowledge, in order to evaluate and exploit emerging technological opportunities.

A firm's capacity to modify its technological competences is limited, and takes a long time (Rosenbloom and Cusumano, 1987). In addition to intra-firm constraints on the directions of technological accumulation, both home country and industry characteristics influence firm's rate of competence accumulation. Firms' innovative activities are often articulated to processes of knowledge relatedness (Breschi, Lissoni and Malerba, 2003), resulting in a pattern of technological change that usually comprises an incremental and path dependent trajectory. This process is also influenced by knowledge spillovers based on specific technologies, being, for the most part, intra-sectoral (Malerba et al., 2013). However, a process of technological diversification is also very important in order to prevent innovative firms from being locked in a specific technology (Susuki and Kodama, 2004) or in a less dynamic trajectory. In this context, technological diversification increases the level of potential exploration and reconfiguration of existing knowledge into new fields of research, allowing a more fruitful exploitation of firms' combinative capabilities (Kogut and Zander, 1992). Large firms' technology portfolios tend to be highly diversified, and technological diversification levels usually exceed the diversification levels of product portfolios (Gambardella and Torrisi, 1998; Pavitt et al, 1989; Patel and Pavitt, 1997; Leten et al, 2007). Another relevant aspect refers to the costs associated with the exploitation of the R&D potential, which might be reduced with the diversification to new promising technologies.

One of the driving forces of the diversification of large firms' technology portfolios involves the increasing complexity of products and production processes over time (Rycroft and Kash, 1999; Hobday, Davies and Prencipe, 2005), which makes it necessary for companies to invest in a variety of technological fields. This investment remains a necessity because an effective assimilation of externally acquired technologies requires the presence of 'absorptive capacity' (Cohen and Levinthal, 1989; Granstrand, Patel and Pavitt, 1997). The absorption capacity of an organization refers to its ability to learn, assimilate and use knowledge developed elsewhere through a process that involves substantial investments, especially of an intangible nature (Cohen and Levinthal 1989). This capacity crucially depends on the learning experience, which may be enhanced by in-house R&D activities. The concept of absorption capacity tells that in order to be able to access a relevant piece of knowledge developed elsewhere it is necessary to perform internal R&D on something similar (Saviotti 1998). Thus, R&D serves to a dual, but strongly interrelated, role: first, to develop new products and production processes, and second, to enhance the capacity to learn and to absorb external useful knowledge.

There are different potentially positive effects of technological diversification in terms of firm's technological performance. The access of knowledge from multiple fields increases the potential of cross-fertilization, yielding new inventions and functionalities and improving product and process performances (Granstrand, 1998). A broad technology base may also enable firms to create completely new products and services resulting from the combination of knowledge from different technology fields (Argyres, 1996; Hargadon, 1997; Kodama, 1992). According to Kodama (1992), this process may be reinforced by the impact of so-called ‘technology fusion’ innovations that have become more and more important over time. As an example, the rise of mechatronics and bioengineering implies a movement towards the ‘fusion’ of knowledge from different fields, which reinforces the relevance of knowledge portfolios diversification at the firm level. Diversified firms might be able to outperform focused or less diversified firms when technological relatedness allows such synergies to be enacted (Van Looy, Martens and Debackere, 2005).

At the same time, the potential for synergy might depend on the technological coherence of a firm’s technology portfolio. A technology portfolio is coherent when it combines technologies that share a common knowledge base, rely upon common scientific principles or have similar heuristics of search (Breschi, Lissoni and Malerba, 2003). In this context, the trend towards a persistency in the composition of firms’ technology portfolios over time can be related to the nature of the innovation process that takes place within firms, reflecting a cumulative process of incremental innovation efforts related to problem definition and solving activities (Rosenberg 1982). As many problems are firm specific, the learning experience of a firm is usually very distinctive. Due to the distinctiveness and cumulativeness of firm’s learning experience, their technological trajectory can be characterized as unique and path-dependent (Dosi, 1982; Dosi et all, 2008; Garud et all, 2010).

2.2 - The use of information about patents citations in the analysis of firms' competences

A rigorous analysis of firms' competences requires the identification of a complex set of fragmented pieces of knowledge generated inside and outside their boundaries, which has to be integrated and mobilized in order to increase their innovative performance. One of the main alternatives to identify relevant pieces of technological knowledge comprises data from patents. This analytical perspective assumes that patents cover a broad range of technologies including some that have few other sources of data. We can also establish a close (but imperfect) link to invention, since most significant inventions from businesses tend to be patented, whether based on R&D or not. Each patent document contains detailed information about the invention process: the identification of the inventors (name, address) and applicant (owner), a reasonably complete description of the invention, the technological field concerned, the citations of previous patents and scientific articles related to the invention, etc. Moreover, unlike survey data directly collected from the firms, which are usually protected by statistical secrecy laws, patents data are public.

Among the topics of the literature that uses patent data we can mention the analysis of firms' (or other organizations) technological performance, as well as their levels of technological specialization and/or strength. Firms build their intellectual property portfolios, trade patents, sell licenses, and create patent pools with other firms. Compared to other output indicators such as publications, patents are a better indicator of activities that are closer to technological developments. They help to track technological leadership and the position of firms in a given technology field or area (*e.g.* through indexes of revealed technological advantages), as well as how they change over time. In some industries, patents have a critical strategic importance, such as in the pharmaceutical industry, in which the patent of only one molecular structure it is not sufficient for the efficient protection of the invention. Firms in other industries are also getting more active in patenting. Plasmans *et al.* (1999) advocate that the entrepreneurial innovative behavior can be explained reasonably well by the firms' patenting behavior.

Considering the complexity of the subject, the measure of technological competencies through patent data is inherently imperfect. The citations listed in the patent application refer to prior patents with similarities and complementarities to the technology for which protection is sought. Research in this area uses both "backward" and "forward" citations to measure knowledge flows. Backward citations are citations to other patents made by the surveyed firms, which have been used to measure technological knowledge acquired by the patenting entities studied. This helps to track knowledge spillovers in technology, permitting to estimate the obsolescence curve of technologies, the diffusion of knowledge emanating from specific inventions to institutions, areas, regions, etc. Forward citations are citations to the firm's patents made by other patents, which have been interpreted as a measure of the knowledge diffusion outward from the patenting entity. These citations permit to assess and evaluate the technological impact of inventions, *e.g.* their cross technology and/or geographical impact, being used as a proxy for patent value or importance. The existence of different types of citations permits to generate two groups of indicators. The first group comprises indicators based on backward citations, and the second group comprises impact-type indicators, based on forward citations.

More recently, several academic studies have proposed to organize patent data in terms of aggregated citation structures among IPC classes (Kay *et al*., 2012; Schoen, 2011; Leydesdorff et all, 2012). The aggregated citation matrices at the 3-digit and 4-digit level of IPC are normalized using the cosine as a similarity measure among citation distributions in different classes (Ahlgren *et al*., 2003). Jaffe (1986) defined "technological proximity" and "technological distances" in terms of that cosine measure. Considering a three-dimensional matrix between patent classes, we can denote an element of this matrix by c_{ijt}, where the subscripts i, j, and t denote, respectively, the spillover generating (cited) technical field, the spillover receiving (citing) technical field, and the citation lag. In these matrices, a forward linkage is taken as a case where a technical field "supplies" technology spillovers to other fields, and a backward linkage is taken as a case where a technical field "takes" spillovers from other fields. As in the input-output literature, the analysis establishes a hierarchy of sectors according to their importance in terms of forward and backward linkages by means of a triangulation of the spillover matrix. The triangulation procedure does not provide, in itself, a numerical measure of backward or forward relatedness. Rather, it is the relative order of technical field that gives an indication of the importance of backward and forward linkages. A technical field ranking at the top (bottom) of the triangulated matrix has relatively strong (weak) backward linkages and weak (strong) forward linkages.

The use of patent citations to map and analyze knowledge flows requires some qualifications. Part of them involves common problems in the use of patent statistics as source of information, discussed by Griliches (1990). Among the more severe problems, are the facts that different sectors have different "propensities to patent," and that patent statistics do not measure very well innovative activities in small firms. There are also differences among technologies and sectors in the effective importance of patents as protection against imitation. We can also mention some potential limitations to the use of patents in the analysis of firms' competences. Despite the fact that patents do not measure the extent of firm's external technological linkages, many studies have shown (Cohen and Levinthal, 1989) that those linkages are in general complementary to internal competencies. It is also important to consider that patents measure only codified knowledge, whereas a high proportion of firm-specific competencies comprise non-codified (i.e. tacit) knowledge, but we can argue that the two forms of knowledge are complementary, not substitutes (Patel and Pavitt, 1987). Furthermore, patents do not accurately measure competencies in some technological areas (software, for example) but we can admit that this bias may be compensate by a satisfactory coverage of information in related technological areas.

Griliches (1990) and Jaffe et al. (1993) discuss the advantages and the problems of using patent citation data to capture knowledge exchange. In this sense, it is important to discriminate which citations reflect knowledge spillovers between the inventor of the cited patent and the citing patent. Concerning this issue, we might consider that the examiner or the inventor can add citations. While in the latter case we can reasonably presume that citations provide a signal about the existence of some kind of relationship between the sender and the receiver, in the former case the interpretation is less favorable. The patent examiner has the right to add other citations that he/she finds applicable in the given case, even though the inventor may not be aware of the inventions added. Jaffe, Trajtenberg, and Fogarty (2000) and Jaffe and Trajtenberg (2002) reported that 'at most' half of the patent citations mention previous work of which inventors were unaware. Addition of new citations by the patent examiners is widely practiced in the USPTO (United States Patent and Trademark Office), and the EPO (European Patent Office). However, for the majority of US patents published in databases it is not possible to effectively distinguish between the 'original' citation and a citation added by the examiner. We can consider those added records as an indication of knowledge spillovers, which are not officially recognized by the inventors, but from which he or she could have benefited as well, reflecting some kind of "noise" in the analysis of spillovers that not invalidate the use of patent citations as satisfactory "proxies" of knowledge flows.

The relationship of patent citations with unobserved flows of technological knowledge can be thought of as an analogy to citations in academic articles, but there are important limitations to this analogy. Like bibliographic citations, patent citations are supposed to indicate previous works in which the current work builds or relies, or which embodies results related to those of the current work. Patent citations have the advantage of perform a legal function related to the validity of the patent and the technology to which it applies, not being affected by unnecessary citations of friends, colleagues, or famous people. Patent citations capture only the knowledge flows which occur between patented 'pieces' of innovation, underestimating other means of knowledge transfer that are not effectively captured by patent citations. These means include the purchase of capital goods with embodied technologies, the employment of engineers and other creative staff from other firms and institutions, the voluntary knowledge exchange at conferences and in scientific publications, etc. (Dumont and Tsakanikas, 2001). We may also consider that information on patent citation is meaningful only when used comparatively. There is no natural scale or value measurement associated with citation data, so the fact that a given patent has received

10 or 100 citations does not indicate whether that patent is "highly" cited. In other words, the evaluation of the citation intensity of an invention, an inventor, an institution, or any other group of reference, can only be made with reference to some "benchmark" of citation intensity.

Different approaches to analyze knowledge flows from patent citation data have been proposed. Verspagen (1997; 1999) uses patent citation data from USPTO to build a technological proximity matrix, measured by the number of citations between patents from different technological classes, which are linked to a sectoral classification through a technological flow matrix. In the analysis the author builds a matrix where knowledge comes from the sector which filed the citing patent toward the sector of the cited patent. Patent citations are also used to measure the degree to which two firms' technological capabilities overlap - that is, the extent to which their technological resources come from the same pools of technological knowledge. Technological overlap between two firms could be measured by their 'patent cross-citation rate' or 'common citation rate', each of which measures different aspects of technological overlap. The common citation rate measures the degree to which firms share the same external technology 'pool', and firms with a higher common citation rate therefore exhibit a higher degree of technological overlap. It is possible to use patent citations to trace a publicly visible stream of technological knowledge flows because patent citations document the 'relation' between citing and cited actors (Podolny, Stuart, and Hannan, 1996; Stuart and Podolny, 1995; Gomes-Casseres, Hagedoorn, and Jaffe, 2006). Duguet and Mac Garvie (2005) found that patent citations have more chances to emerge between firms with joint activities which may lead to knowledge transfers (R&D cooperation, allowing the use of someone else's inventions, firm acquisition, joint venture). Even when we consider citation links across patents as "noisy" indicators of knowledge, those flows tend to be mediated by face-to-face communication, since senders and receivers need to exchange bits of knowledge that escape from full codification. Consequently, the existence of a citation link between two patents may signal the existence of a social link between the inventors responsible for those patents.

3 - Firm competences, innovative performance, and growth strategies of IBM: general trends

The next sections seek to use information about patent citations to track and discuss the evolution of competences and knowledge flows in the case of a globally diversified firm, IBM. This case is illustrative because it involves a leading company in its respective sectors of activity, which has undergone important transformations, reflecting a process of convergence and technological fusion, due to the impact of new digital technologies. The general outlines of IBM's history are extensively discussed in the literature (Dittrich, Duysters and de Man, 2007; Gerstner, 2002; Hamel, 2000; Meyer et al., 2005a, Balgodin and Pandit, 2001; Ghandour et al., 2004; Hemp and Stewart, 2004; Takahashi and Namiki, 2003). IBM's recent trajectory reflects the moment when the firm faced a fierce competition in the early 1990s. During this period, IBM"s leadership position started to deteriorate due to the rise of UNIX, the control over the operating system microprocessor components of PC gained by Microsoft and Intel, the emergence of new competitors for hardware components (such as Fujitsu, Digital Equipment and Compaq) and the growing ground gained by firms specialized in information services (such as EDS and Andersen Consulting). In this context, a critical event occurred in April 1993, when Louis Gerstner was appointed as CEO with the aim of transforming IBM in order to regain its competitive position. This strategy was supported by two forces that emerged in the computer industry: i) a process of system integration, originated from customer demand (Curry and Kenney, 1999; Ghandour et al., 2004; Hemp and Stewart, 2004; Meyer et al., 2005b); ii) the emergence of the networked model of computing that would replace the stand-alone PCs, generating the management of an enormous flows of digital information in large-scale systems (Curry and Kenney, 1999; Sweeney, 1998). Along with this transformation, IBM became an organization more flat and flexible, able to adapt more quickly and more adequately to a rapidly changing competitive environment, gradually exiting commodity hardware technologies and concentrating on higher-margin software, services and integrated (e-business) solutions.

By 1992, the services unit of IBM was responsible for only 27 percent of revenues, while the software unit did not even exist. Contrastingly, in 2001, after important reorientations, services and software were responsible for sales of $35 billion and $13 billion respectively, representing 58 percent of total revenues. During this process, IBM's market cap increased from $30 billion in 1993 to $173 billion in 2001, with the share price being multiplied by seven. At the end of 2000's, IBM has continued this transformation, reaching $91 billion in revenues, more than 70% from software and services. During a 20-year period, IBM has evolved from a technology company based on hardware to a broad-based solutions provider, constituting a remarkable example of the new world of open systems and on-demand capabilities.

The experience of IBM was investigated by Miozzo and Grimshaw (2011), who examined how new kinds of large services firms that have emerged from outsourcing of business functions developed their organizational capabilities. The main challenge for these firms comprise the development of distinctive capabilities that permits the generation of "integrated solutions", combining client specific knowledge, from different sectors of the economy, with corporate-wide processes that capture and diffuse a common system of routines across all different projects and countries of operation. For the development of integrated solutions, a "critical interface" in knowledge transfer functions (Pavitt, 1998) is the relationship with the clients, including strengthening of multiple forms of supplier–client engagement in the innovation process. Such features are discussed in the literature about innovation in services (Eiglier and Langeard, 1987; Gadrey 1992; De Bandt and Gadrey, 1994; Gallouj, 1994, 2002; Gallouj and Gallouj, 2000; den Hertog, 2010, Miles, 2005, 2008, 2010). Dittrich, Duysters and de Man (2007) discuss the case of IBM as an example of radical redirection from an exploitation strategy towards an exploration strategy, with its focus progressively changing from a hardware manufacturing company to a global service provider and software company.

Along with this process, IBM was able to reconfigure its "dynamic capabilities", in order to refresh its success in mature businesses, such as mainframe computers, as well as to move into new ones, such as digital media (Harreld et all, 2007). A new focus comes from the perception that customers would increasingly value companies that could provide solutions that integrate technology from various suppliers and, more importantly, integrate technology into their processes. The core competence required to execute this strategy would involve the ability to integrate systems in order to solve customers' business problems—open middleware (the software that allows applications across a variety of platforms) and services. To transform itself into an "on-demand business" using advanced computer and software technologies to quicken the flow of knowledge, IBM had to structure an open architecture, providing a transformation of the company around customer needs, bringing together experts to solve customer problems—not simply to sell products or services.

The recent evolution of IBM's revenues and gross profit margin reflect the process of continuous transformation of its core business. Three fundamental shifts have transformed IBM's strategy. The first is due to the strategic perception that data is becoming the world's new critical resource, being converted in new basis of firm's competitive advantage. The second assumes that the emergence of cloud is transforming IT and business processes into digital services, becoming the path to new business models. The third conceives mobile technologies and social networks as fundamental means to transform individual engagement, creating expectations of security, trust and value in return for personal information, with a new systematic approach to engagement being required. Based on this perception, IBM accelerated its growth through a movement that involves the improvement of "digital" content in their relations with clients. Through this process, IBM has integrated units to make it easier and quicker to put together solutions drawn from an expanding digital portfolio, accelerating growth and enhancing client experience. In a new stage of this process, digital business is supposed to converge with a new kind of digital intelligence, what IBM call as "cognitive business". Cognitive systems form a category of technologies that use natural language processing, speech and image recognition, computer vision and machine learning to enable people and machines to interact more naturally. This system allows to extend and magnify human expertise and cognition, providing expert assistance in a fraction of the time it now takes, being based around a domain specific semantic model.

Reflecting the effort made along these last 20 years to reconfigure its capabilities, 80% of IBM's currently revenues come from clients who have deployed cross-IBM solutions. In 2015 IBM revenues by segments comprised a share of 43% generated by Technology Services and Cloud Platforms, 22% by Cognitive Solutions, 21% by Global Business Services and 14% by Systems & Financing. IBM strategy has focused in the achievement of a more stable revenue performance, based on the divestment of lower margin businesses and the investment in higher value businesses, generating an expressive cash flow that supports both reinvestment and shareholders returns. From 2005 to 2015 its revenues decreased from US$ 91 billion to US$ 82 billion, while its gross profit margin grew from 40% to 51%, reflecting a significant improvement driven by a mix of higher value and productivity. IBM business model is based on a strong generation of free cash flow, which reached approximately $13.1 billion in 2015, permitting to invest more than 6 percent of its revenue in R&D and about $4 billion in capital expenditures, including 15 acquisitions (Murphy, 2016).

IBM annually invests approximately US$ 6 billion in R&D, mobilizing competences from a broad range of disciplines at its Research Centers, including the areas of Behavioral

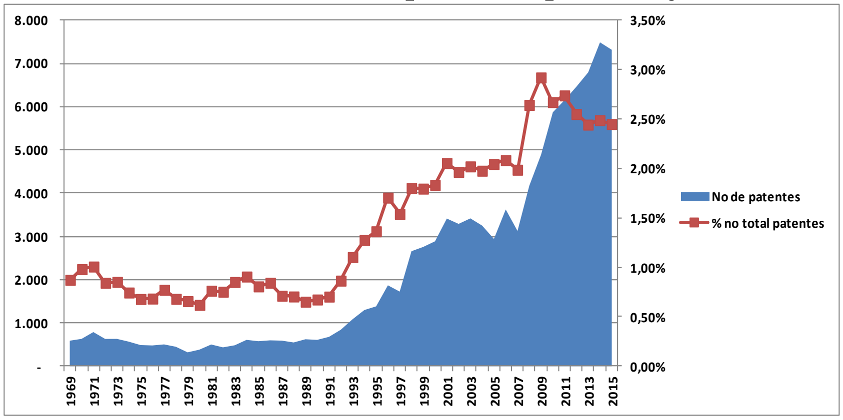
Sciences, Chemistry, Computer Science, Electrical Engineering, Materials Science, Mathematical Sciences, Physics, Service Science, Management and Engineering (Reeves, 2012). Actually, IBM R&D activities are scattered around the world among 12 main laboratories located in six continents, mobilizing more than 3.000 researchers. IBM's global research labs are focused on four key areas: 1) Industries and Solutions, focused on the transformation of business through data; 2) Computing as a Service, which intend to advance all areas surrounding the transformation of IT through Cloud; 3) Cognitive Computing, comprising the consolidation of teams focused on next generation IBM capabilities; 4) Science & Technology, reflecting investments in fundamental science to advance in core technologies that will create the future of computing and enable this new mode

We can also observe that, in 2015, for the 23rd consecutive year, IBM became the leading company in U.S. patents earned, breaking the 7.000 threshold (IBM, 2015). Even more important than the total number, is the transformation that those patents represent. When the reconfiguration began more than two decades ago, 27 percent of IBM’s patents were in hardware, while in 2015 IBM had seven times as many total patents as before, and 31 percent of them were in cloud, analytics and cognitive technologies. Along with this process, IBM has transformed its portfolio— shedding businesses that provided little differentiating value to its clients, shifting R&D focus and making dozens of acquisitions to fuel its growth businesses. At the same time, efforts were made to inject new thinking and talent into IBM’s culture—such as training 60,000 employees in Agile methods and increasing the team of professional designers to more than 1.000, embedded with clients in 23 design studios around the world. Throughout this trajectory, IBM diversification to multiple technological areas tends to be reinforced with the growing focus on cognitive systems.

4 - Patent citations and the evolution of firms' competences and knowledge flows: evidences collected from IBM

Figure 1 shows information about the evolution of the number of patents deposited by the company in the USPTO. The following analysis will be based on patent citation data of IBM, extracted from the USPTO database for the years 1974, 1982, 1990, 1998 and 2006. This data comprise information about citations extracted from patents filed by IBM and about citations extracted from patents of other companies citing its patents. In addition, the analysis will consider information obtained from technological interaction matrices which crosses the information of OST technological domains on patents of a certain company with the technological domains to which those patents recourse to make their citations. The evaluation for these five years permits to show the evolution of the number of citations, the companies mentioned and the technological domains related to those citations.

Figure 1 - Evolution of the number of patents deposited by IBM in the USPTO



Source: Own elaboration based on data extracted from USPTO Database

IBM has significantly increased the number of patent citations deposited at the USPTO, which evolves from 295 companies in 1974 (including IBM itself) to 534, 972, 3.417, and 5.652 registrations in the subsequent years (1982, 1990, 1998 and 2006, respectively), as illustrated by **Table 1.** The growth in number of total citations is also very evident in IBM's case, highlighting the relevance at absorption of external knowledge. While in 1974 IBM's patents cited 908 patents, equivalent to 3.08 citations per patent, in 2006 this amount reached 39.757 citations, equivalent to 7.03 citations per patent. Despite the higher number of citations achieved in 2006, the highest citation rate per company occurred in 1998 with 8.27 citations. IBM also presented an increasingly impact in terms of knowledge provided and absorbed by other companies. While in 1974 a total of 286 companies (including IBM itself) cited this company in their patents, in 2006 this amount reached an impressive number of 4.912 companies. A similar increase was observed in the number of citations of IBM's patents made by these companies, which rose from 902 in 1974 to 68.274 in 2006, resulting in a growth of IBM's average patent citation per company from 3.15 in 1974 to 13.9 in 2006. The last three lines of **Table 1** seek to compare whether IBM absorbs more knowledge or has its knowledge absorbed more intensively by other companies. Thus, it may be noticed that although IBM cited a larger number of companies in its patents than was cited in other companies' patents, in almost every year except 1990, the number of citations of IBM patents by other firms is generally higher than IBM's patents citations of other firms. That is, the company not only stands out as a major technology producer, but also contributes to the generation of knowledge absorbed by other companies.

Table 1 - General Data about Patents Citations of IBM

	1974	1982	1990	1998	2006
Cited Assignees from IBM patents	295	534	972	3.417	5.652
Number of Citations in IBM patents	908	2.225	4.347	28.271	39.757
Citations per assignee in IBM patents	3,08	4,17	4,47	8,27	7,03
Assignees which Cite IBM Patents	286	510	1.060	2.654	4.912
Number of Citations of IBM patents	902	2.651	6.434	28.246	68.274
Citations per assignee of IBM patents	3,15	5,20	6,07	10,64	13,9
Ratio between Assignees which Cite IBM Patents and Cited Assignees from IBM patents	0,97	0,96	1,09	0,78	0,87
Ratio between Number of Citations of IBM patents and Number of Citations in IBM patents	0,99	1,19	1,48	1,00	1,72
Ratio between Citations per assignee of IBM patents and Citations per assignee in IBM patents	1,02	1,25	1,36	1,29	1,98

Source: Own elaboration based on data extracted from USPTO Database

Aiming to further analyze the evolution of IBM's patents citations, some traditional indicators of concentration applied in studies of Industrial Organization may be employed. One of these indicators, the Concentration Ratio (CRn), measures the percentage of citations mentioned in the patents of a given company attributed to a set of n companies, considered in a decreasing order according to the number of citations. Specifically, this indicator comprises the "Cited Assignees" from the patents of a given company. Alternatively, it is also possible to consider an equivalent indicator calculated from the number of citations incorporated in patents of other companies that mention the company in question, considering a set of n companies, ordered in a decreasing order according to the number of citations. In this case, the indicator refers to "Assignees which Cite Patents" of a given company. According to these criteria, CR1, CR4 and CR10 were calculated. Another indicator comprises a traditional Herfindhal-Hirschman Index (HHI), which measures the general concentration of the citation sample, calculated from the sum of the square of the participation of each company, both for cited patents ("Cited Assignees") as well as for patents citing the company ("Assignees which Cite Patents"). The index has a higher value when all citations belong to a restricted number of companies and tends to zero when the number of companies cited or citing the company's patents in question is more diversified. In terms of their absolute values, the indicators are located between 0 and 1 in such a way that the closer to 0 the less concentrated are the citations. The objective is to evaluate IBM's patents citations concentration along the periods.

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Table 2 presents information about the distribution of companies cited in IBM's patents and information about the distribution of companies that cite IBM in their respective patents. The data based on selected concentration indexes indicate a decrease in concentration for all indicators. However, despite this general movement, some characteristics can be highlighted. The CR_1 represents IBM's participation in each of the dimensions considered. In 1974, IBM itself produced 24.6% of all patents cited by IBM, and this proportion declined to 19.6% in 2006. This trend suggests that the company has reinforced the search of external knowledge in order to provide new patents. The drop in CR_1 was even greater for those companies that cited IBM, indicating that a more diverse number of firms is using the knowledge generated within that company.

Table 2: Concentration Indexes for Patents cited by IBM and for patents citing IBM

Cited Assignees from IBM patents	1974	1982	1990	1998	2006
CR_1	0,246	0,274	0,210	0,198	0,196
CR_4	0,370	0,363	0,285	0,281	0,272
CR_{10}	0,472	0,462	0,381	0,377	0,362
HH	0,070	0,081	0,050	0,045	0,043
Assignees which Cite IBM Patents	**1974**	**1982**	**1990**	**1998**	**2006**
CR_1	0,246	0,193	0,140	0,205	0,118
CR_4	0,339	0,293	0,240	0,276	0,239
CR_{10}	0,442	0,406	0,348	0,370	0,339
HH	0,067	0,046	0,028	0,047	0,022

Source: Own elaboration based on data extracted from USPTO Database

The analysis of other concentration indexes for cited patents also confirms the tendency towards a deconcentration of the number of companies cited by IBM. The CR_4 index decreased from 37,0% in 1974 to 23,9% in 2006, while the CR_{10} index shows a decrease from 47.2% to 36.2% over the same period. Both groups of the top four or top ten companies that appear in the calculation of these indicators have undergone major changes over the period considered. In 1974, the firms most cited by IBM in its patents, excluding itself, were Bell Telephone, RCA and US Phillips , respectively, while in 2006 this group of companies was formed by Microsoft Corporation, Sun Microsystems and Intel Corporation. The HHI showed a small increase between 1976 and 1984, dropping significantly throughout the subsequent period, evolving from 0.081 in 1984 to 0.043 in 2006.

Another way of analyzing is to focus on the evolution of technological fields related to the companies' patents with the highest citations incorporated in IBM's patents . Considering a sample of the 10 companies with the highest number of patent citations from IBM, some technological fields stand out. Specifically, we can mention coded technological fields 1 to 7, as well as the fields 15, 16 and 24, which are remarkable along all the temporal cuts [1].On the other hand, it is worth noticing the significant growth of citations in some technological fields along the period, such as the codified fields 8, 21, 27 and 35[2]. It is noteworthy that IBM cited all the 30 technology domains at least once in the patents deposited in 2006, evidencing a process of diversification regarding the knowledge bases that the company seeks to access.

According to **Table 2**, it is observed that the concentration indexes are also falling when we consider the patents of others companies citing IBM. According to CR_1 index, IBM is the

[1] The correspondent technological fields are: 1 – Electrical components; 2 – Audiovisual ; 3 – Telecommunication ; 4 – Information Technology; 5 – Semiconductors ; 6 – Optics ; 7 – Analysis , measurement and control; 15 – Surface technology and coating; 16 – Material Processing; 24 – Handling and printing.

[2] The correspondent technological fields are: 8 – Medical engineering; 21 – Machine tools; 27 – Nuclear engineering; 29 – consumer goods and equipments.

company that quotes more intensively its own patents, but this share decreased from 24,6% in 1974 to 11,8% in 2006, indicating a greater openness regarding the absorption of knowledge generated by IBM by external agents. The CR_4 decreased from 33.9% to 23.9% over the same period, while the CR10 decreased from 44.2% to 33.9% to the citations in patents of other companies mentioning IBM. This trend also indicates an increase and diversification of the number of agents that absorb knowledge generated by IBM in their innovative efforts. The HHI index related to assignees which cite IBM's patents also achieved a general reduction over the period considered, going from 0.067 in 1974 to 0.022 in 2006, despite an increase between 1990 and 1998, with a subsequent fall.

These values demonstrate that IBM's role in providing new knowledge has being reinforced, deconcentrated and expanded along the period. The companies that most cited IBM in their patents in 1974 were Honeywell Information Systems, Bell Telephone Laboratories Incorporated and Burroughs Corporation. In 2006, by contrast, these companies were Microsoft Corporation, Micron Technology and Intel Corporation. Considering the OST technological fields, it is noted that the fields associated with the patents of companies cited by IBM in its patents are quite similar to those linked to the patents of other companies that cite IBM's patents. However, we can mention three other technological fields related to the patents of the 10 companies that most mention IBM's patents, linked to codes 17, 18 and 22[3]. These technological fields might be mentioned as mainly absorbers of the knowledge generated by IBM. The diversification of these fields demonstrates the relevance of IBM to generate knowledge absorbed by others companies with technological efforts directed to extremely varied fields.

It is also possible to consider data extracted from technological interaction matrices which cross the information of the 30 patents technological fields. Specifically, we study all possible combinations of patent's technological fields (expressed in the rows of the matrix) and technological fields cited in the patents (expressed in the columns of the matrix). The total number of cells is 900. It is important to remark that a citation can be counted in more than one cell when it belongs to more than one technological field. That is, if a patent includes citations in the field of telecommunications and information technology, for instance, when it is incorporated in the matrix it will appear in those cells corresponding to these two characteristics. Another point to notice is that a patent is counted the number of times it is cited . Taking this fact, it is observed that IBM increased the number of citations in the different technological domains from 43.680 in 1974 to 563.225.

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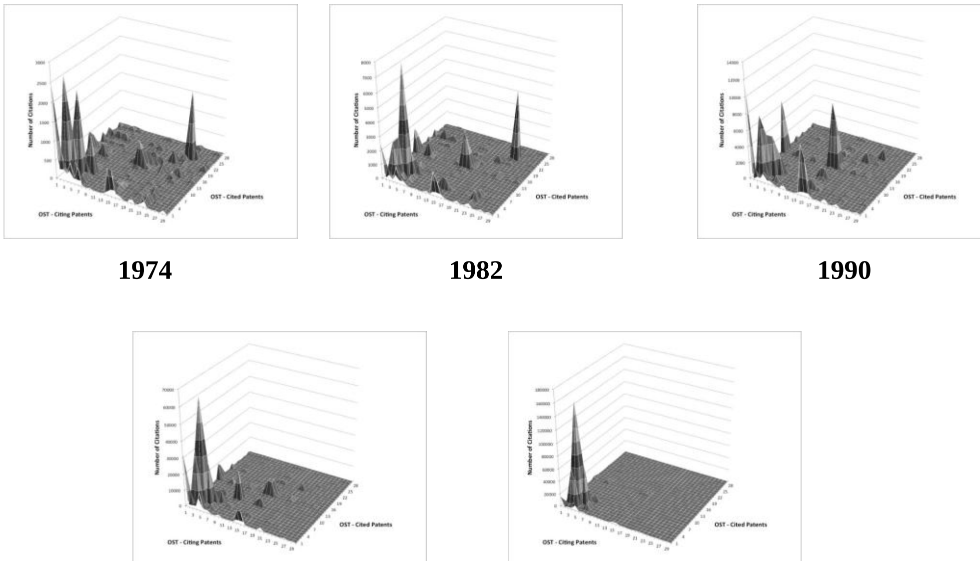
[3] These correspondent technological fields are: 17 – Material and metallurgy; 18 – Thermal techniques; 22 – Engines, pumps and turbines.

Figure 2 – Evolution of Patent Citations of IBM extracted from Technological Interaction Matrix



1974 **1982** **1990**

1998 **2006**

Source: Own elaboration based on data extracted from USPTO Database

Initially the concentration indexes will be presented for the matrices as a whole and then those indexes will be disaggregated into matrices rows and columns . **Table 3** presents the concentration indexes for IBM technological interaction matrix. The table shows that IBM has significantly focused its patents over the years. In 1974 the most cited combination comprised patents in telecommunications citing patents in telecommunication, which accounted for 6.16% of the total citations, as indicated by the index CR_1. This measure has a peculiar behavior since the most cited cell does not repeat from 1974 until 1998. In 1982, the CR_1 represented the patents of semiconductors that cited patents in semiconductors, while in 1990 it comprised patents in electrical components citing patents in electrical components. An important change occurred in 1998, when CR1 became representative of patents in information technology citing patents in information technology. In 2006 this last result was repeated, accompanied by a significant growth of the index.

Table 3: General Concentration Indices for IBM Technological Interaction Matrix

	1974	**1982**	**1990**	**1998**	**2006**
Number of citations	43.680	68.709	133.460	477.546	563.225
CR_1 of the matrix	6,16%	11,55%	9,03%	13,72%	28,89%
CR_4 of the matrix	21,42%	26,80%	25,78%	33,26%	57,69%
CR_{10} of the matrix	33,10%	43,85%	50,10%	48,33%	72,36%
HHI of the matrix	0,017	0,031	0,032	0,040	0,118
Fulfillment Index	53,8%	54,2%	53,8%	76,2%	70,0%
Diagonalization Index	38,2%	42,2%	38,2%	46,6%	58,4%

Source: Own elaboration based on data extracted from USPTO Database

The CR_4 index also shows a concentration movement from 21.42% in 1974 to 57.69% in 2006. The most striking growth occurred during the 1998-2006 interval, for which the index grew more than 24 percentage points. For almost every year of the sample the elements of this index belong to the main diagonal[4]. Only two exceptions can be noticed, the first one in 1990, where the pair of patents for electrical components citing patents for surface technology and coatings appeared in the fourth place. The second one happened in 2006, in which telecommunication patents citing patents in information technology appeared in the fourth place. The CR_{10} also presented a very high value for 2006, indicating that 72.36% of all citations belonged to only ten pairs. This indicator shows a growth of elements located outside the main diagonal. While in 1974 there were two cells with this characteristic among the top ten, in 2006 it rose to four. The HHI index also has grown significantly over the sample years and, like other indicators, increased greatly during the interval of the last two periods. This last indicator reveals that not only the concentration among the largest cells of the matrix increased, but also the general concentration has grown.

It is important to observe that, despite the trend towards the concentration of citations in certain fields, IBM also increased patent citation for virtually all areas in the matrix, with one of the few exceptions being patents for electrical equipment citing patents of electrical equipment for the last two periods, indicating a relative deviation from the areas linked to electro-mechanical based technologies. At the end of the period sampled, the cell referring to the patents in the information technology field citing patents in information technology, with 162.717 citations, was almost 2.5 times higher than the second ranked cell, comprising patents in telecommunications citing patents in telecommunications, with 65.771 citations. In 1974 this difference among the top two cells was only 1.07 times and the two largest combinations were telecommunications citing telecommunications and electrical equipment citing electrical equipment respectively. Thus, although the concentration is evident in the matrix of technological interactions, it does not hide the absolute increase of citations in several areas of knowledge, evidencing the complexity of the process of technological absorption within the company. Such trends can be illustrated by the analysis of two additional indicators presented in **Table 3**. The "Fulfillment Index" of the technological interaction matrix comprises the total percentage of cells in which citations were identified. This percentage rose from 53.8% in 1974 to 76.2% in 1998 and to 70.0% in 2006, indicating a process of "openness" of IBM to a greater number of knowledge fields. However, this process occurred simultaneously with a higher concentration of citations in certain knowledge areas directly linked to some "core competences" of the company. A more detailed analysis of these fields indicates that these "cores" have gradually evolved from the areas of semiconductors and electrical components to the area of information technology, which is consistent with the company's process of competitive repositioning discussed in the previous section.

It is also possible to refer this analysis to the concentration observed in the rows and columns of IBM's technological interaction matrix. The rows represent the concentrations

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[4] The main diagonal cell comprises citations linked to patents of a certain technological area with citations linked to patents of the same area.

of the technological fields most mentioned by the company in terms of its patent's respective fields. The columns represent the concentration of citations present in company's patents linked to the selected technological fields. **Table 4** reinforces the hypothesis that IBM's patents have focused over the years.

Table 4: Concentration Indices for Rows and Columns of IBM Technological Interaction Matrix

	1974	1982	1990	1998	2006
Rows- Citations in patent fields by technological domains					
CR1 rows	15,42%	18,32%	22,74%	20,15%	41,08%
CR4 rows	49,00%	55,88%	64,20%	58,77%	81,10%
CR10 rows	86,31%	90,82%	90,80%	92,11%	96,16%
HH rows	0,089	0,105	0,131	0,114	0,236
Columns - Citations in technological domains by patent fields					
CR1 columns	15,57%	16,76%	21,68%	17,96%	37,22%
CR4 columns	42,75%	52,70%	62,29%	55,21%	77,98%
CR10 columns	77,63%	86,84%	88,68%	89,20%	94,80%
HH columns	0,075	0,096	0,121	0,104	0,209

Source: Own elaboration based on data extracted from USPTO Database

The CR_1 of the rows reached 15.42% in 1974, referring to patents for electronic components. It should be noticed that the most cited matrix cell in that year was the combination of patents on telecommunication citing patents in telecommunication. However, the patent's technological domain that makes most citations in all technological domains was the field of electrical components. In 1982, this characteristic was attributed to semiconductors, returning to the electrical components domain in 1990 and evolving to information technologies for the years 1998 and 2006. The CR_4 index calculated for the rows has also increased significantly over the years. However, some observations can be made based on the composition of this measure. While in 1990 the citations related to patents in information technology and semiconductors did not belong to the group of the most cited technological domains, they came to occupy the first and second top positions in 2006. On the other hand, while in 1990 patents in surface technology and coating and in material processing were the second and third most cited technology fields, they no longer appeared among the four top domains in 2006. The CR_{10} index for the rows has presented high values since 1974, evidencing that many of the patents that cite other sources belong to a relatively narrow group of technological domains. It was observed that, within the latter group, there were few changes over the period considered. It is also observed that the HHI index showed a significant increase in the last period, going from 0,114 to 0,236. Much of this trend is due to the increase in citations related to patents in information technology, which evolves from the fifth place among the most cited patent field by technology domains between 1974-1990 to the first place between 1998-2006 (see **Table 5**). .Another analysis that helps to corroborate this evidence is to focus on the HHI indexes calculated for each row of the matrix. In 1974, the information technology patents had an HHI of 0.208, which rose to 0.623 in 2006. This evolution corroborates the tendency captured by the analysis of the general concentration of the technology interaction matrix.

A similar behavior was also observed for the domain of semiconductors, which is even more concentrated, with an HHI index of 0.699 in 2006.

Table 5 - - Most cited patent field by technology domains of IBM's patents and Most cited technological domains by patent fields of IBM's patents - 1974, 1982, 1990, 1998 and 2006

1974	1982	1990	1998	2006
Rows - Most cited patent field by technology domains				
1. Electrical components 2. Telecommunications 3. Semiconductors 4. Handling and printing 5. Information technology 6. Surface Technology and coating 7. Material Processing 8. Audiovisual 9. Analysis, measurement and control 10. Machine tools	1. Semiconductors 2. Surface technology and coating 3. Electrical components 4. Handling and printing 5. Informational technology 6. Material processing 7. Telecommunications 8. Optics 9. Analysis, measurement and control 10. Audiovisual	1. Electrical components 2. Surface technology and coating 3. Material processing 4. Telecommunications 5. Information technology 6. Semiconductors 7. Optics 8. Macromolecular chemistry 9. Machine tools 10. Handling and printing	1. Information technology 2. Electrical component 3. Telecommunications 4. Semiconductors 5. Material processing 6. Surface technology and coating 7. Macromolecular chemistry 8. Audiovisual 9. Analysis, measurement and control 10. Optics	1. Information technology 2. Telecommunications 3. Semiconductors 4. Analysis, measurement and control 5. Electrical components 6. Audiovisual 7. Material processing 8. Surface technology and coating 9. Optics 10. Macromolecular chemistry
Columns - Most cited technological domains by patent fields				
1. Electrical components 2. Telecommunications 3. Semiconductors 4. Handling and printing 5. Information technology 6. Surface technology and coating 7. Material processing 8. Analysis, measurement and control 9. Audiovisual 10. Optics	1. Semiconductors 2. Electrical components 3. Surface technology and coating 4. Handling and printing 5. Material processing 6. Information technology 7. Telecommunications 8. Optics 9. Analysis, measurement and control 10. Audiovisual	1. Electrical components 2. Surface technology and coating 3. Material processing 4. Telecommunications 5. Semiconductors 6. Information technology 7. Optics 8. Macromolecular chemistry 9. Machine tools 10. Handling and printing	1. Information technology 2. Electrical components 3. Telecommunications 4. Semiconductors 5. Surface technology and coating 6. Macromolecular chemistry 7. Material processing 8. Audiovisual 9. Analysis, measurement and control 10. Optics	1. Information technology 2. Telecommunications 3. Semiconductors 4. Electrical components 5. Analysis, measurement and control 6. Audiovisual 7. Surface technology and coating 8. Material processing 9. Optics 10. Macromolecular chemistry

Source: Own elaboration based on data extracted from USPTO Database

A similar analysis might be extended to the columns of the interaction matrix. Initially, it is worth mentioning that although these citations also tend to become more concentrated, the movement was smoother than the observed in the rows. In 1974, the technological domain of electronic components was the most cited, corresponding to 15.6% of the total. The most relevant fields cited migrated to technological domains of information technology, semiconductors and telecommunication. In 2006, information technology was responsible for 37.2% of all citations, but also in this dimension it can be noticed that the concentration was lower than in the case of the rows (41.1%). The HHI index calculated for the columns evolved from 0.075 in 1974 to 0.209 in 2006, evidencing the same movement found in the rows, but in a slightly softer trend. Also in the columns, we observe an increase in the cited technological domain of information technology, which evolves from the sixth place among most cited technological domains by patent fields between 1974-1990 to the first place between 1998-2006 (see Table 5). .In particular, the technological domains related to citations in information technology and semiconductors have been significantly concentrated, which contributes to reinforce the trend found in the matrix as a whole.

5 - Concluding Remarks

Citations in patents can be used not only to trace information sources on which invention was built, but also to analyze knowledge flows from firm to firm, as well as from other sectors and from different technological domains. The analysis tried to correlate the management of knowledge flows and the (re)construction of firms' competences to the evolution of patent citations, exploring data from USPTO to investigate this process in the recent trajectory of IBM, a globally diversified firm.

In the case of IBM, the strategy shifted dramatically from the early 1990s, reflecting a process of business reorientation and capabilities reconfiguration, in the direction of services, software and digital media. Through this process, IBM evolved from a technology company based on hardware to a broad-based solutions provider, constituting a remarkable example of the new world of open systems and on-demand capabilities. Along this trajectory, IBM has significantly increased the number of patent citations deposited at the USPTO, evidencing an increasingly impact in terms of knowledge provided and absorbed by other companies. Considering information about the distribution of companies cited in IBM’s patents and information about the distribution of companies that cite IBM in their respective patents, we observed a decrease in concentration of all indicators, which suggests that IBM's role in providing new knowledge has being reinforced, deconcentrated and expanded along the period. Considering the technological fields related to the patents of the companies with the highest citations incorporated in IBM’s patents and of other companies’ patents that most cited IBM, there are evidences of a significant diversification of these fields, reinforcing the role of IBM as a nucleus that simultaneously absorb and generate knowledge to others companies.

Considering data extracted from technological interaction matrices, it is noteworthy that IBM cited all the 30 technology domains at least once in the patents deposited in 2006, evidencing a process of diversification regarding the knowledge bases that the company seeks to access. The evidences collected show that IBM has significantly focused its patents citations over the years, evolving progressively from citations in telecommunications, semiconductors and electrical components to citations in information technology. However, IBM also increased patent citation for virtually all areas in the matrix. The evolution of the "Fulfillment Index" of the technological interaction matrix indicates a process of "openness" of IBM to a greater number of knowledge fields. This process occurred simultaneously with a higher concentration of citations in certain knowledge areas directly linked to some "core competences" of the company. A more detailed analysis of these fields indicates that these "cores" have gradually evolved from the areas of semiconductors and electrical components to the area of information technology.

Our analysis assumes an exploratory character and should be further complemented and expanded. Considering some analytical paths mentioned by the literature, we could refer to some possible outcomes to be explored in other analyzes. In the innovation literature, data about patent citations tend to be used not only to measure knowledge flows or spillovers, but also to evaluate patent quality and to analyze the strategic behavior of companies. The use of patent citations in the study of knowledge flows might also be complemented by the use of citation function to measure the probability of citations between patents. We can also consider an index of citation impact related to forward citations, as well as indexes of generality (to forward citations), originality (to backward citations) and geographical impact of a patent. Furthermore, patent citations can be useful to measure the degree to which firms' technological capabilities overlap, that is, the extent to which their technological resources come from the same pools of technological knowledge. This indicator could be constructed by their 'patent cross-citation rate' or 'common citation rate', which measures different aspects of technological overlap. The existence of a citation link between two patents may also signal a social link between their inventors, which could exchange their knowledge directly or via some common acquaintance. In this sense, it is possible to use concepts taken from modern network science and social network studies to evaluate the structure of technological flows using data from patent citation to construct a network structure. It is also possible to use patent citations as a proxy to measure flows of technological knowledge between companies engaged in inter-firm R&D collaborating, in inter-organizational relations or in operations related to associations, mergers and acquisitions.

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