

Measuring Innovation Quality: A Patent Analysis

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Abstract : *Patents have been widely used in innovation literature as a reliable and meaningful measure of innovation performance. However, existing research has mostly used the mere number of patents as a rough indicator of innovation success, lacking to provide insights on innovation quality. Additionally, less is known about how firms are grouped in highly competitive markets and which are the strategies adopted in their inventive activities. To better understand these dynamics, this paper aims to investigate the innovation quality of firms operating in a high-tech industry employing multiple patent-based indicators. Explorative findings on patent strategies as well as patent trends are discussed.*

Keywords – *innovation, patents, quality, technological impact, originality, generality*

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I. Introduction

Patents have been broadly used in innovation literature as a reliable and meaningful measure of innovation performance [1], [2], [3], [4], [5], [6], [7], [8], and [9]. By definition, patents grant to their owners an exclusive monopoly over the use of a novel, non-obvious, and industrially applicable invention. Inventions may require time to be granted, and the whole patenting process may be costly for firms and inventors. Hence, the inventions protected are expected to be valuable for firms allowing them to generate rents from their future commercialization [10], [11], and [12]. Thus, patents can unveil insights on firms' inventive and innovation activities.

Early innovation research has used R&D outputs (i.e., the number of patents) as a rough indicator of innovation performance [13], [14], [15], and [16]. More specifically, [17] found that the value of a firm patent portfolio is concentrated in a few patents. Also, [18] recognized that the number of patents is not a good measure of innovation performance because it does not capture the patents' importance. Instead, [18] observed a close relationship between patent citation-based indicators and value of innovation. Later, [19] validated patent citations as a better indicator of technological impact and importance in comparison to the simple patent counts.

Although the existing studies have widely analyzed the patent and R&D relationship proposing different models [20], they lack to provide insights on the quality of innovation and particularly on how firms are grouped in highly competitive markets according to the strategies adopted in their inventive activities. To better understand these dynamics, this study examines 155 firms operating in the U.S. communications industry. This context was chosen because innovation in this industry is essential for firms to compete successfully and gain a competitive advantage [21], the high-density of the patenting activity [22], [23], and the usefulness of patent analysis if applied to this industry [24]. Innovation quality measures, namely, technological impact, the invention's originality, and generality have been calculated. We also account for the size of patent portfolios. Cluster analysis and technology trends have been considered for the investigation of industry homogeneity and search strategies. Explorative findings are discussed.

This paper is organized as follows. In section 2, we summarize the literature background on patent analysis and indicators of innovation quality. Section 3 is devoted to the methodology applied, whereas in section 4, we describe the primary results obtained. Finally, discussion, conclusion, limitations, and future research are included in section 5.

II. Literature Background

Patent analysis is a widespread method used to transform patent information into in-depth insights on firm innovation performance [25]. The innovation literature has pointed out the significant correlation between R&D input and inventive performance, highlighting the relationship between the R&D expenditure and the number of patents produced [21] and [26]. In particular, [27] showed that product innovations are likely to be protected by patents while process innovations often are protected by secrecy. The other interesting relationship is the one related to patents and financial performance: if a firm grants patents frequently, it means that it has sufficient capabilities to generate inventions, affecting the economic returns positively. Because firms decide to

patent for multiple reasons, patent analysis represents a useful tool for investigating firm strategies. For instance, most firms grant patents to find intellectual protection, to increase their reputation, to improve their position in negotiations; other firms choose to grant patents for creating barriers along essential inventions and consequently block their competitors.

Furthermore, patent analysis is used for monitoring innovation trends, identifying technological change and convergence at a firm- and industry-level [20], [29], and [30]. Indeed, [12] gauged technological change using not only innovation surveys but also patents. Additionally, patent trends can be used to analyze technology patterns and trajectories, [31] showed that the rapid increase of the patenting activity in the '90s reflected the substantial increase of the R&D expenditure. Besides, [32] showed that the analysis of the technology trends is more reliable when examining big portfolios, the bias rises significantly for firms with a few patents. Patent analysis can be used in the evaluation of mergers and acquisitions, and alliances, referring to the different aspects concerning the transaction, for example, the targeting, the due-diligence, the target's or acquirer's inventive performance [7], [8], and [9].

More specifically, innovation scholars have shown a great interest in analyzing patent citation data [7], [8], [9], [33], and [34]. Patent citation analysis is a bibliometric technique that links patents in the same way that the science citations link the papers' references [33], [35], [36], and [37]. Patent citations have been primarily used in three lines of research: as a measure of patent quality [1], [2], [3], [4], [5], [6], [7], [8], [18], [38], as a measure of knowledge flows and spillovers [39], [40], [41], and as a tool for the examination of technology structure [33], [42]. The term "quality" has been often used to emphasize both the technological and value dimensions of innovation [43]. [18] was the first to introduce patent forward citations as a measure of innovation quality suggesting that patents with a high number of forward citations are the most valuable. [40] used citations as proxies for both technological impact and knowledge spillovers. [44] used patent citations to measure the R&D impact. [45] showed that the size of the invention is positively linked with citation counts. [47] used citation-based patent stock as patent indicator and assumed that the economic value of a single patent is proportional to its forward citations, similarly to R&D. [48] showed that citation stocks have a significant impact on Tobin's q . Firms that own highly cited patents show the ability not only to innovate but also to influence further technological developments [24]. The number of forward citations can be used as a proxy for patent quality [45] and [46]. [49] observed that patent citation information is useful for investors to judge the future profit-earning potential of firm innovation activities. [50] found that firm market value increases at the time patents receive citations as they are perceived a signal of portfolio importance. Moreover, a patent may cite non-patent literature; this often happens in the pharmaceuticals where patents are highly connected with scientific research [25].

Following [18] and [38], in this paper we conceive the quality of innovation in terms of technological impact of an invention, originality, and generality. The measure of impact regards the technological importance of patent [43]. A high number of citing patents suggests that many subsequent inventions have been built upon that specific technology. However, [48] showed that a patent granted recently cannot be fully appreciated using patent citation analysis because it needs time before the accumulation of information on its forward citations. The originality index was first introduced by [51] and then resumed by [38]. This measure indicates the breadth of technological knowledge synthesized in an invention [7], [8], and [9]. If an invention is built upon different technology domains, it is considered to be more "original." Higher the number of these technology fields, higher the invention's degree of originality is expected to be. The generality index measures the breadth of applicability of an invention across different technology domains. When patent citations belong to many different technology fields, it means that the technology embodied in the focal patent can be considered "general" across domains [51].

III. Methodology

In the last decades, the communications industry has been the protagonist of several revolutions such as the diffusion of voice, data, and video transmission. In the U.S.A, one of the most critical events in this industry occurred in 1984 when the monopolist AT&T was subdivided into several companies allowing the rise of firms like Time Warner, Hughes Electronics, and Qualcomm Wireless. According to [21], the communications industry is one of the industries in which innovation is fundamental to the firms' survival, and firms have myriad of patents. Also, [22] and [23] showed that semiconductor firms have a high-density patenting activity. [38] observed that the communications industry has the highest inventions' generality of applicability in a broad range of technology fields, further making this industry interesting for a more in-depth analysis. [24] suggest that the patent analysis is not useful in all sectors, but it is more applicable to the telecommunications, information technology, pharmaceuticals, biotechnology, chemicals, and automotive [33]. Hence, a patent analysis is particularly suitable for this industry.

In this study, we selected 155 firms operating in the U.S. communications industry between 1995 and 2009. We chose this time frame to capture the internet bubble as well as the digital transformation experienced

during these years. Patent information was retrieved using the Derwent Innovation Index database; the sample included more than 120.000 patents and their citations, both backward and forward. Finally, we applied cluster analysis to gather firms according to their degree of similarity along four variables: technological impact, originality, generality, and the size of the patent portfolio.

Variables

Following the methodology proposed by [38], backward and forward citations were used to measure the indicators of innovation quality, namely, technological impact, originality, and generality. The gauge of technological impact captures the influence of a patented invention on subsequent inventions; higher is this influence, higher will be the number of citations an invention receives. The measure of technological impact is calculated as the total number of forward citations. As citations are influenced by time, the value of this indicator has been normalized using the industry average for each specific year. Moreover, we considered the size of the patent portfolio calculated as the simple count of the number of patents.

In particular, the originality index considers the classification codes of the backward citations and it is calculated as follows:

$$Originality_i = 1 - \sum_{j=1}^{n_i} s_{ij}^2 \tag{1}$$

s_{ij} represents the forward citations of patent i (expressed in percentage terms) that belong to the classification code j , out of n_i patent technology classes. Patents whose backward citations are classified under the same code will have an originality index equal to zero. The value will rise as the number of technology classes goes broader.

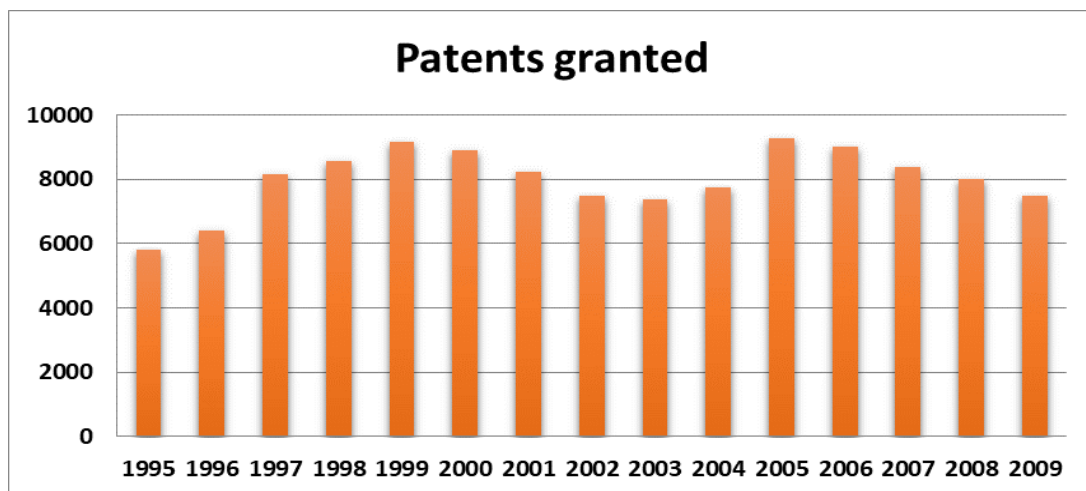
The generality index captures the degree of applicability of a technology on further inventions. Different from the originality index, the generality index uses the information extracted from forward citations. It is defined following [38] and [51]:

$$Generality_i = 1 - \sum_{j=1}^{n_i} t_{ij}^2 \tag{2}$$

t_{ij} represents the forward citations of patent i (expressed in percentage terms) that have classification code j , out of n_i classification codes. Patents having their forward citations spread on many technology domains will have a high value of this indicator.

IV. Results

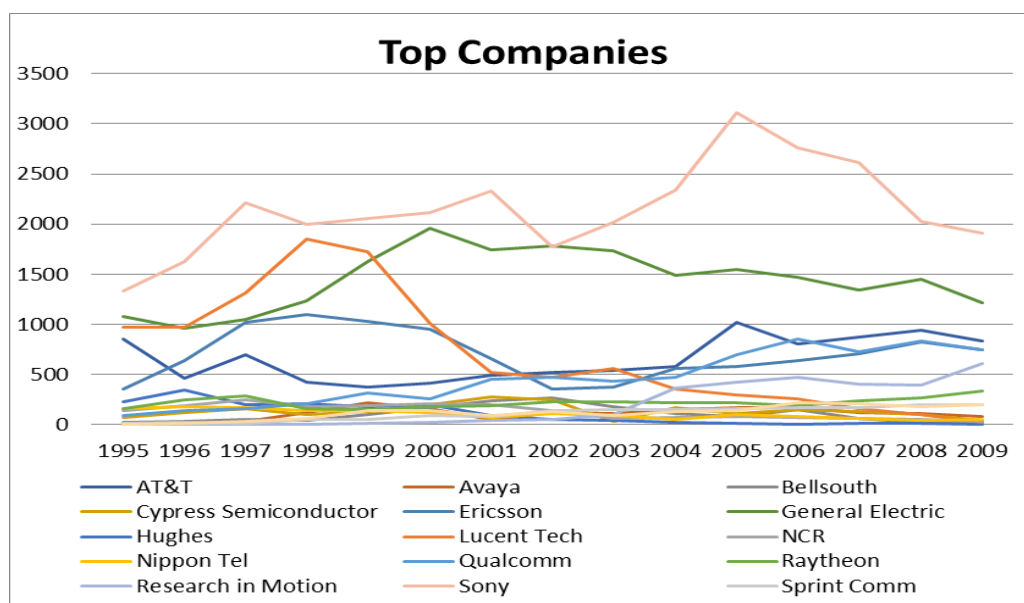
Graph 1 shows the number of patents granted in the 15-year timespan. Two picks are observed, the first in 1999 and the other in 2005, additionally, there are two decreases of the industry’s patenting activity, the first with the burst of the internet bubble and the second after 2005. The pick of 2005 with 9.255 patents granted is strongly influenced by the intensive inventive activity of firms such as Sony Corp., General Electric Co., and AT&T.



Graph. 1: The Patents of the 155 companies examined.

Graph 2 depicts patent trends for firms with more than 1.000 patents. Now it is clear the significant influence of the patent portfolio of Sony Corp. Also, AT&T follows a similar pattern like Sony Corp., although with fewer patents; both have picks in 1997 and 2005 and then a constant decrease. Interestingly, the patenting

activity of Lucent Technologies dropped from 1998 to 2009. It should be added that Lucent Technologies in 2006 was merged with Alcatel, for this reason, the number of patents might have fallen drastically. In contrast, Research in Motion, a very little company formed in 1984, at the beginning it had a few patents while in 2009 its portfolio included 608 patents.



Graph. 2: Trend of the patent counts for top companies.

Table 1 summarizes the results of the cluster analysis with four variables (technological impact, originality, generality, and size of the patent portfolio), four groups emerge. Table 2 includes a high-low innovation quality for each cluster.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
AT&T	AAT	8x8	ACT Tel
Ericsson	Allied	Arch Wireless	Advanced Telecom
General Electric	Americ Mob Sat	ATG	Alere
Lucent Tech	Americ Telecare	Atlantic Signal	Ameritech
Qualcomm	Armstrong World	Avaya	Broadband Wireless
Sony Corp.	Cablevision	Bellsouth	Calamp
	Centennial Tech	Black Box	Century Comm
	Certegey	CenturyLink	Clearwire
	Charter Comm	Cogent Tech	Corridor Systems
	Coherent Logix	Comm and Power	Crown Castle
	Comcast	Cox Comm	EMS Tech
	Consolidated Edison	Deutsche Telekom	Flash Comm
	Cypress Semiconductor	DirectTV	Global Tel
	EchoStar	FTS	Globalstar
	Enron	Hughes	Integra Tech
	Equinix	Infowave Software	Intercontinental Exchange
	First World Comm	Insight	Intrado
	Gemstar TV Guide	Intek Global	Iridium
	General Dynamics	Inter Tel	LCC
	ICG	ITXC	Mediacom
	IDT	Leap Wireless	Mediaone
	iGo	Level 3 Comm	Motient
	Inflow	Loral	Net Talk
	InPhonic	MCI	Netro
	Intellectual Discovery	Nippon Tel	Network Solutions
	Interactive Data	Pittway	Nextel
	J2	Premier Tech	NTS
	LodgeNet	Research in Motion	Omnipoint
	Long Distance	Reynolds&Reynolds	PC-Tel
	Metrocall	RSL Electronics	Pokertek
	NCR	Rural Technologies	Ptek Holdings

Neon	Simtek	Purple Comm
Net2Phone	Sprint Comm	Stratos Global
Novatel Wireless	Telenor	SunGard
Optel	Transaction Network	TCI International
Orbital Sciences	TSR	Teleport
Orix	Tyco Submarine	TeliaSonera
Panamsat	Tyco Telecom	Teligent
Pegasus	Valor Communication	T-Netix
Polycom	Vanguard Semiconductor	TV Guide
Public Service Solutions	Verizon	Usinternetworking
Q Comm	Virgin Mobile	UTStarcom
Quebecor	Voice Signal	WorldQuest
Qwest Comm	Western Digital	XO Comm
Raindance Comm	WorldCom	
Raytheon		
Ses Americom		
Spectrasite		
Sunrise Telecom		
Syniverse Tech		
Telkonet		
Time Warner		
TiVo		
United States Cell		
Unity Semiconductor		
Viacom		
Voom		
Williams Comm		
Winstar Comm		
Xpedite Systems		

Table 1: Cluster analysis

Indicators	Low	Medium-Low	Medium-High	High
Technological Impact	Cluster 4	Cluster 2	Cluster 3	Cluster 1
Originality	Cluster 4	Cluster 1	Cluster 3	Cluster 2
Generality	Cluster 4	Cluster 3	Cluster 1	Cluster 2
Size of Patent Portfolio	Cluster 4	Cluster 2	Cluster 3	Cluster 1

Table 2: Innovation quality for each cluster

As expected, the most prominent firms, Sony Corp., General Electric, Lucent Tech., AT&T, Ericsson, and Qualcomm are included in the same group (Cluster 1). The most impactful patents belong to Sony Corp., General Electric, and Ericsson, whereas Qualcomm has the lowest value of technological impact followed by Lucent Technologies, and AT&T. The generality index captures the breadth of applicability of an invention across various technology domains and firms in Cluster 1 show a medium-low generality index and not the highest one. This result can be explained by the strategy adopted by these firms, they might have focused their inventive activity efforts on a few but well-developed technologies. The top generality index for this cluster is observed for General Electric, Sony Corp., and Lucent Technologies; in the lowest positions, there are Ericsson, AT&T, and Qualcomm. Surprisingly, the results regarding the generality index of firms in Cluster 1 are similar to those of originality index. As explained in the previous paragraphs, originality represents the breadth of the technology streams synthesized in a patented invention. General Electric seems to have built its patent portfolio on broader technologies suggesting a high-quality patent portfolio, followed by Sony Corp. and Lucent Technologies.

Firms included in Cluster 2 show a medium-low technological impact with high values for both generality and originality indicators. Firms with patents characterized by the highest technological impact are Raytheon followed by Cypress Semiconductor, NCR, Unity Semiconductor, Qwest Communications, Time Warner, General Dynamics, Polycom, and Comcast. Generality index is high for firms with very small portfolios such as Pegasus followed by AAT. Focusing on firms with a portfolio with more than 100 patents the highest generality index is observed for Unity Semiconductor, Armstrong World, Cypress Semiconductor, Polycom, Time Warner, Raytheon, NCR, General Dynamics, Qwest Communications and Comcast. Similarly, the highest originality index is observed for firms having a few patents, Long Distance, Interactive Data, Optel, Public Service Solutions, and AAT. When selecting top-10 companies, the podium is composed of Armstrong World, Raytheon, and NCR. The subsequent firms in this ranking are Polycom, Time Warner, Comcast, Cypress Semiconductor, Unity Semiconductor, General Dynamics, and Qwest Communications.

Cluster 3 consists of firms with medium-high technological impact and medium generality and originality indicators. The top-10 firms with the highest technological impact are Research in Motion, Verizon Communications, Bellsouth, Avaya, Sprint Communications, Hughes, MCI, Nippon Tel, Western Digital, and WorldCom. Research in Motion followed by ITCX, Arch Wireless, MCI, Inter Tel, Tyco Submarine, Bellsouth, Infowave Software, Avaya, and Reynolds & Reynolds, have the highest generality index. Firms with the highest originality value have very small portfolios, less than 10 patents in 15 years; this is the case of Rural Technologies, Intek Global, Atlantic Signal, Blackbox, Transaction Network, Vanguard, Valor Semiconductor and Valor Communications. If we consider the most significant portfolios (companies with more than 500 patents), the highest values of originality index are recorded for DirecTV, Hughes, MCI, Research in Motion, Western Digital, Avaya, Verizon Communications, Nippon Tel, Bellsouth, and Sprint Communications.

Finally, Cluster 4 encloses the companies with the lowest indexes. The worst position is for Teligent, Purple Communications, Usinternetworking, Crown Castle, Corridor Systems, SunGard, and Ptek Holdings. All these companies, have a low technological impact, low generality, and originality indexes and also a small number of patents. If we focus on the lowest performing firms regarding originality and generality of patent portfolios with more than 50 patents, there are Clearwire, TeliaSonera, Advanced Telecom, Alere, NTS, EMS Technologies, Nextel Communications, Globalstar, Omnipoint, Mediaone, Network Solutions, UTStarcom, and Ameritech.

V. Discussion And Conclusion

The present study investigated the innovation quality of firms operating in the U.S. communications industry. We grouped firms according to four patent indicators, the size of the patent portfolio, technological impact, originality, and generality. We further analyzed the industry patent trends. Results showed that large patent portfolios were spanned on a relatively small number of technology fields, suggesting a strategy focused on a better development of firm “core” technologies. The generality index confirmed this strategy because medium-low values signify a relatively narrow breadth of applicability of the patented inventions. However, these firms possessed impactful patents, their influence was higher than the industry average, denoting the presence of breakthrough innovations. These inventions had significant influence but they were not applied in a broad range of technology domains.

Moreover, the indicator of originality had a similar pattern like the generality index highlighting how big firms might have chosen search strategies on narrow technology fields. In contrast, firms with the highest originality and generality indicators had a medium-sized portfolio, showing how firms were trying to gain a competitive advantage and to establish their position in the market. Often, a high generality index is associated with high originality index denoting how the considerable inventive breadth embodied in the patent is reflected on subsequent inventions granted. Firms with a minimal number of patents behaved unpredictably, especially concerning generality and originality indicators. Some of them recorded the highest generality and originality indexes of the whole sample; others had the worst performance. The high variability points out how small firms were still exploring to survive in a market occupied by established firms.

Furthermore, firms that fell in the same cluster were likely to cooperate through alliances or to engage in M&A. The most important transactions were the joint venture of Sony-Ericsson and the acquisition of MCI by Verizon Communication. The actors seemed to follow a similar strategy and to be complementary. In the case of Sony-Ericsson, they possessed different but brilliantly-developed “core” technologies, so both of them gained an advantage from competitive cooperation and increased their market share.

This work contributes to the innovation literature by highlighting the innovation quality dynamics and search strategies at an industry level, specifically by grouping firms according to their size of patent portfolio and quality of innovation. It also contributes to the identification of industry innovation trends. Future studies might focus on the phenomenon of M&A and strategic alliances investigating how these events shape the acquirers’ inventive activities. Finally, among the limitations worthy to note, is the fact that not all the inventions are patented because they do not fulfill the patentability conditions or because firms may rely on secrecy.

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