Emerald Competitiveness Review

INTERNATIONAL CONNECTIVITY IN THE GENERATION OF INFORMATION AND COMMUNICATION TECHNOLOGY (ICT) IN SPAIN

Journal:	*Competitiveness Review*
Manuscript ID	CR-08-2019-0072.R1
Manuscript Type:	Empirical Research Paper
Keywords:	Knowledge sources, ICT, Patents, International Connectivity

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ABSTRACT:

Purpose – The purpose of this paper is to analyze the characteristics of knowledge creation in a key technology field such as ICT, to determine whether it is driven by domestic firms and inventors, or whether the traction is provided by international connections to global innovation networks. We argue that the geographical pattern of international connectivity is characterized by local concentration and strongly connections to foreign MNEs, for which a large number of inventors in Spain work.

Design/methodology/approach –The analysis was done using data from the United States Patent and Trademark Office (USPTO) database, covering almost 40 years, ranging from 1976 until 2014. We used patents in the ICT sector connected to either inventors or organizations located in Spain. We analyzed collaboration by the location of both inventors and assignees, and the connections established across borders. Second, we assessed the level of concentration and dispersion that characterizes these relationships.

Findings – First, the growth of the ICT sector in Spain is strongly driven by linkages with foreign companies, in particular those located in the U.S. Second, the interaction of local and international clusters of knowledge generation is a key driver of the ICT sector, which is far from being global. Third, there is a geographic concentration of national/international knowledge sources, which is mediated by the technological strategies of internationalized firms. Therefore, the new information age seems to be highly dependent on the collaboration between individuals and companies through focal local points, and on the prevalence of co-developed international inventions.

Research limitations/implications – Understanding the patterns of ICT-related knowledge creation and its geographical footprint is crucial to foster competitiveness in the digital age. The transition from a paradigm based on tangible assets to one where competitive advantage stems mainly from intangibles, has significant implications for both policy and practice. International collaboration presents opportunities to enhance competitiveness at various levels, be that organizations, regions, or countries. To seize these opportunities, it is key to enhance the endogenous capabilities and absorptive capacity of the local players. While patent data captures the output of a national innovation system only partially, it is still a suitable indicator to capture international connectedness. More qualitative-oriented techniques, however, may allow for a better assessment of tacit knowledge flows.

Originality/value – The creation of knowledge in high-tech industries is a key aspect of competitiveness, and it is increasingly supported by collaboration that spans across borders. However, knowledge creation adopts different patterns, depending on the unique characteristics of the country. We analyze the case of Spain, a developed economy with pockets of innovation but also significant areas that can be considered "peripheral", both economically and industrially, when compared to much of Western Europe. Our analysis captures the combination of concentration and dispersion in the process of knowledge generation that characterizes the ICT sector in intermediate countries.

Keywords: Knowledge sources; ICT; Patents; International Connectivity.

Paper type Research paper

1. INTRODUCTION

The interest in the analysis of the international connectedness of Spain, and more specifically in the field of information and communication technologies (ICT), is driven by its central role in the digital age, and the fact that ICT development is a determinant factor of a country's competitiveness. This sector requires substantial R&D efforts and a solid technological base, amplifying the critical need to be connected to internationally-dispersed knowledge networks. Intangible assets (such as knowledge and information) play a central role as a source of competitive advantages that are largely determined by the innovativeness level of countries. This dynamic defines a positive relationship between intangible assets and economic growth.

The use of ICT is more critical today than in the past, not only creating opportunities but also raising new challenges, in areas such as artificial intelligence, the internet of things, and machine learning. This also imposes important changes to the way companies are organized. Artificial intelligence may allow multinational companies to identify market niches, and to develop innovations in real time (Iammarino et al., 2017). Therefore, this sector can leverage the complementarity of tangible and intangible assets as an essential element for the development of innovation activities, and the establishment of collaboration networks among different actors.

This paper explores the patterns of international collaboration for the generation of ICT knowledge between Spain and other countries. We reveal a pattern in which international dispersion and national concentration coexist. Our analysis is conducted by utilizing patent data from the United States Patent Office (USPTO), for the period 1976-2014. The analysis of individual and organizational linkages in innovation-related development processes has been used in previous analyses, as an effective tool to understand the patterns of international dispersion of activities involving tacit knowledge creation (Cano-Kollmann et al., 2014), and in some specific industry studies (Lei et al., 2013).

A second objective of this paper is to identify the location of Spanish inventors, in order to analyse the geographical distribution inside the country, at the regional level. Spain is ranked as a moderate innovator country within the European context, especially in high-tech sectors (European Commission, 2017), and notable regional disparities persist. This has led to the creation of strategic alliances in order to obtain external knowledge when technological complexity increases (Guellec and Van Pottelsberghe, 2000). These pipelines through which knowledge circulates are usually centered around particular hubs within the country. These connectivity networks allow countries that are not at the forefront of innovation, the acquisition and transmission of tacit knowledge, which is usually not available in the relatively shallow domestic knowledge pools. These collaborations, often lead to the codification of knowledge via patenting.

The structure of the paper is as follows: in section two, we review existing literature, with a particular focus on the importance of patents as an indicator of internationalization and the ICT sector in Spain. In section three, we describe the methodology used, the characteristics of the USPTO[1] database, and the references for the identification of technological categories. Section four contains the main findings related to international collaboration through co-invented patents in the ICT sector. Finally, we present concluding remarks in section five.

2. BACKGROUND

2.1. Internationalization of technology and innovation

[1] Patent data obtained from the PatentsView platform.

The pioneering contribution of Archibugi and Michie (1995) identifies the different dimensions of the internationalization of technology -exploitation, international collaboration, and global generation. International connectivity is present in all these dimensions. In particular, the relevant aspect of such connectivity is the relationships established among inventors located in different countries who work together for the development of innovations. Innovation systems are becoming increasingly complex and more geographically spread, while the global value chains describe a map integrated by more fine-sliced and disaggregated activities across borders that has also effects in the technological and innovation sides. These developments and processes contribute to an increasing interconnectedness of countries. Knowledge, even within clusters, does not circulate freely. It tends to remain within relatively closed “epistemic communities”, centered around experts in each particular field (Lissoni, 2001). Within the networks of these epistemic communities, inventors who hold patents tend to be more central, which means they tend to be hubs through which knowledge and information circulates (Balconi et al., 2004). Therefore, even though patents can be the “tip of the iceberg” within a national innovation system, they are vital to the identification of those epistemic communities and hubs where knowledge production and transmission concentrates. This is particularly important in the case of intermediate countries such as Spain (Álvarez and Molero, 2005), which depend on linkages to other centers of excellence in order to complement their relatively shallow pools of knowledge. Furthermore, since globalization has facilitated the access to new knowledge regardless of location (Archibugi and Lammarino, 2002), as well as globalizing competition (Narula and Hagedoorn, 1998), mapping those relationships makes the footprint of these networks very transparent.

International collaboration is motivated by its direct benefits, and enabled by the rapid progress in telecommunications and transportation, which increases coordination and reduces organizational costs (Narula, 2003). The establishment of collaborative activities for the generation of new knowledge in different contexts defines an open innovation strategy. This includes collaborative alliances with other organizations, contracting out R&D activities, intellectual-industrial property management, and the search for external sources of knowledge (Chesbrough, 2003; Cano-Kollmann et al., 2016).

As Cantwell and Santangelo (1999; 2000) argue, tacit knowledge is not easily codifiable, it is difficult to communicate, imitate, or measure, and its transmission often requires face-to-face interaction. Generation and diffusion of knowledge increasingly depends on the combination and exchange of tacit information (Polanyi, 1966; McFadyen and Cannella Jr, 2004). Activities involving tacit knowledge are geographically dispersed only when knowledge is locally integrated, unique and specialized or, when there are complex organizational networks in place (Cantwell and Santangelo, 1999; 2000). The latter implies that the "international dispersion of activity is led by technological leaders" (Cantwell, 1995), meaning that only leading firms possess the capacities to carry out this type of R&D effectively through geographically dispersed teams.

2.2. Patents as a measurement of internationalization

Patents generally reflect the result of successful R&D activities, and often provide detailed information on such activities. Patent documents are also rights granted by the State to the inventors as consequence of the publication of their inventions, for a specified period of time and under certain conditions. This gives the inventors exclusive rights over the commercial exploitation of said inventions. Therefore, patent data represent a valuable source of information related to technological development and collaboration. Industrial property rights have been widely used as representation of the accumulated explicit technological knowledge (Patel and Pavitt, 1997).

Papers framed within the resource-based view and those centered on capabilities, frequently make use of patents as a measure of the internal creation of technological knowledge; that is, as an indicator of innovation (Hannigan et al., 2015; Alcacer et al., 2016). Patent analysis is also appropriate for the investigation of the collaborative relationships that occur in inventive activities. Therefore, information about co-invention can be used to build maps of the complex social networks to measure their structural properties (Wasserman and Faust, 1994). Accordingly, Cantwell and Santangelo (1999) use patent data granted to the largest companies in the world in the US between 1969 and 1995, following the classification of the USPTO to analyze the international location and dispersion of different types of technology. Likewise, Lee et al. (2016) study the Japanese innovation system through co-invention networks, using the same database for the period 1975-2004. Other studies, such as Cano-Kollmann et al. (2014) and Qiu et al. (2017) use patents to analyze the geographic dispersion of networks of inventors in peripheral regions of Europe.

There are, nonetheless, some limitations in the analysis of patents as an indicator of technological development. The most relevant are that just a fraction of all innovations are patented, and also that some inventions are not technically patentable, because, among other reasons, in certain sectors the life cycle of products is very short (Basberg, 1987, Pavitt, 1998). Another limitation is that patents are deficient indicators of innovation production for sectors in which most innovations are not patented (Hu, 2012). Nonetheless, despite all the difficulties, patent statistics remain a unique source for analyzing the process of technical change and the most valuable inventions tend to be patented in the most important patent systems, particularly in the USPTO. Nothing else approaches it in terms of the amount of data available and the potential industrial, organizational and technological detail (Griliches, 1990).

2.3. The ICT Sector in Spain

Spain, like other advanced economies, has made a great effort to promote the ICT sector, attempting to convert it into a strategic sector. Nevertheless, the situation of relative backwardness in both the endowment and use of ICT in Spain, compared to other leading economies in Europe and the USA, has been a focus of attention for both scholars and policy makers.

Most previous studies about the ICT sector in Spain have focused on its effect on economic growth (Gorriti and Ruiz, 2005; Myro, 2009), as well as on the links between ICT and productivity (Villaseca and Torrent, 2008; Hernando y Núñez, 2002). Villaseca and Torrent (2008) argue that the Spanish ICT industry is very diverse and for this reason, there is ample potential to increase intra-industry collaboration. In a later work, Calderón, (2010), using patent analysis for the period 1999-2007, finds that the liberalization of the ICT sector provided incentives for firms to increase collaboration, likely fostering open innovation within the industry. Valdaliso et al. (2011) studied the Basque Country, a region where policy makers fostered the clusterization of the local economy. They found that the high-technology cluster in the electronics and ICT sectors was one of the most successful. They attributed this to the effectiveness of both intra-cluster and extra-cluster knowledge linkages.

However, despite some pockets of innovation, the level of development in the sector remains below European countries. Rojo and Gómez (2006) concluded that the low number of patents and the low production in international publications, is an indicator of insufficient absorptive capacity and low maturity in the Spanish ICT sector. Others have also described the unimpressive development of the sector, and its small capital stock (Gorriti and Ruiz, 2005; Ontiveros et al. 2004; Núñez, 2001; Banegas, 2003; Bayo-Moriones, & Lera-López, 2007).

This disadvantageous position in such a strategic sector pushed the Spanish government to promote the National Digital Agenda, a program with objectives such as the deployment of networks and services to enhance digital connectivity, the development of the digital economy, increasing the competitiveness and internationalization of Spanish companies, the promotion of R&D in emerging industries, and the promotion of inclusion and digital literacy and the training of new ICT professionals (Ministry of Energy, Tourism and Digital Agenda, 2013).

3. METHODOLOGY

In 1998, OECD countries agreed to define the ICT sector as a "combination of those manufacturing and service industries that collected, transmitted and showed data and information electronically" (OECD, 2002). This was the first step to obtain measurable sectoral indicators[2]. The interest in analyzing the ICT sector is justified by its indirect socioeconomic effects, and its effect in the competitiveness and productivity growth of countries (Lee, 2008). ICT contributes to greater accumulation of capital per worker, and knowledge spillover effects (OECD, 2003). In Spain, the government has tried to promote ICT and the development of the Information Society through a variety of programs, incorporating new technologies in education and training, and aiming at improving SMEs' competitiveness (Álvarez and Magaña, 2007).

Different studies have focused on the relationships between ICT and the analysis of citations using patent data (Corrocher et al., 2007, Shin & Park, 2007, Sorenson et al., 2006). Other authors such as Lee et al. (2009) investigate the co-evolutionary process of the ICT sector in Korea, using the USPTO patent database to estimate both the output and the technological dissemination, while others analyze the technological convergence using the International Patent Classification (Kim et al., 2014).

We use the USPTO patent database for the analysis of the generation of knowledge between Spain and other countries in the ICT sector. This source provides information on inventions almost 40 years old. Notably, not all innovations outside of the U.S. are patented in USPTO. However, because we are trying to understand the connectedness between Spain and innovation networks that span across multiple countries, these collaborations with firms and inventors located around the world are more likely to be captured by the USPTO patents rather than patents filed with the domestic patent offices. This database includes information on all the inventors and assignees listed on each patent, including specific location, and technology classes.

It should be noted that the European Patent Office (EPO) provides information only for countries of assignees and inventors, but no specific addresses. It also requires making individual queries for each type of data. Thus, the USPTO is a more appropriate source to research international connectivity in the ICT sector, and to identify relevant inventors and assignees. Additionally, according to OECD data, there are only 634 ICT patents granted to Spain between 1999 and 2015. The USPTO dataset contains a larger number of patents over a longer period of time.

We pay special attention to patents that reflect a co-invention process, which means a team, rather than an individual, was responsible for the invention. Co-invention has been previously used to explore patterns of collaboration (Ejermo and Karlsson, 2006; Cano-Kollmann et al., 2013). These knowledge networks between inventors, co-located or in different places, are centered around the assignees. The assignee of a patent is the one who owns the patent and, in

[2] ICT includes all forms of technology used to create, store, exchange and process information in various ways, such as data, voice conversations, still or moving images, multimedia presentations and other forms, including those not yet conceived.

most cases, is an organization (a company, a university, a research institution, etc.), although it can also be one or more individuals. In short, considering both inventors and assignees, it's possible to distinguish the following options:

i) Domestic Patents: When both the inventor(s) and the assignee(s) are in Spain.

ii) Internationally connected patent: When at least one assignee or inventor is in Spain and at least one assignee or inventor is located abroad.

Following Cano-Kollmann et al. (2016; 2018), the collaboration for the generation of knowledge can be concentrated or dispersed geographically, given their level of complexity and the participation of inventors and assignees. Thus, we analyze the co-invention of both domestic patents and internationally connected patents, using several indicators to understand to what extent the Spanish ICT innovation system depends on international collaboration for its growth:

1. We measured the number of inventors listed on each patent, which is a basic indicator of collaboration, without distinguishing location.
2. We used a geographical dispersion index, following Hannigan et al. (2015), calculated as follows:

$$Dispersion = 1 - \sum_{i=1}^{N} Si^2$$

where, Si is the share of inventors located in country i and N is the number of inventor countries that appear in a patent. The index is basically an inversion of the well-known Herfindahl index that measures concentration (hence, the addition of "one minus" before the Herfindahl index. It adopts values between 0 and 1, in such a way that 0 would represent zero dispersion (all inventors are in the same country) and the number will approach asymptotically to 1 as the number of countries grow.

3. We calculated the total number of inventor countries each year. This is the number of countries in which the inventors are located. This gives us a more integral measure of geographical dispersion, at the aggregate level rather than the individual patent level.
4. Finally, we calculated what percentage of patents each year are internationally connected, by having either an inventor or an assignee located outside of Spain.

All these indicators, together, give us a very good overview of international footprint of the Spanish innovation system in the ICT sector.

In order to build and measure these indicators, we parsed and edited the original database obtained from the PatentsView platform. The number of patents with Spanish participation (inventor or assignee) was 15,229 patents. We reviewed location to place each patent in the geographical space, and to identify the technological collaboration for the generation of patents between Spain and other countries. Finally, we selected only patents in the ICT sector and analyzed geographical distribution of both inventors and assignees.

The technological classification proposed by Hall et al. (2001), and subsequently called the "NBER technology classification", proposes a simplification of the USPTO patent class taxonomy. While USPTO lists hundreds of classes, the NBER taxonomy classifies them into six categories: 1) Chemical, 2) Computers and communications, 3) Drugs and Medical, 4) Electrical and electronics, 5) Mechanical, 6) Others. There are also 36 subcategories which provide a more fine-grained taxonomy. We selected category 2-Computers and Communications, to identify how many patents corresponded to ICT. Within this category, there are five subcategories: 21) Communications; 22) Computer hardware and software; 23) Computer peripherals; 24) Information storage; and 25) Electronic business methods and software.

The next step was to analyze the temporal evolution of patenting activity associated with Spanish assignees or inventors, based on grant date of related patents, over time. There are two ways to sort patents; the first is by application date, and the second is by grant date. Application date has the advantage of representing the first formal communication of an invention (Schild, 1999; Balconi et al, 2004; Breschi et al., 2007). However, this method produces truncation in recent data, since patent applications from recent years may not have been granted yet (Hannigan et al, 2015). Therefore, we chose grant date. We considered 2014 as the last year of our dataset. Starting in 2015, the USPTO dropped the NBER technology classification in order to adopt a taxonomy called CPC (Cooperative Patent Classes). Therefore, in order to incorporate the years 2015-2018, we should have engaged in a significant manual reclassification effort, matching CPC classes to the previous NBER categories. We believe that such approach would not have changed our results significantly.

4. DISCUSSION OF RESULTS

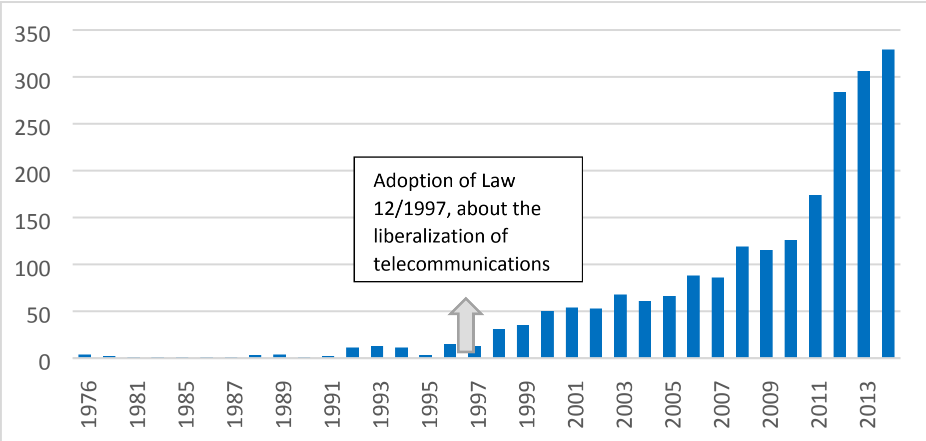
4.1. An overview of Patents in the ICT sector in Spain

In the period ranging from 1976 to 2015, there is a total of 15,229 patents granted that include at least one assignee or one inventor located in Spain. Out of that total, 15% correspond to the ICT category (2 260 patents). We dropped the year 2015 because of the change in classification system, so our final dataset contains 2,132 patents for 1976-2014. Among these patents, 1,604 (75.2%) have one or more foreign assignees, and 950 (44.6%) have one or more foreign inventors. Overall, 1,642 patents (77%) are internationally connected, either through assignees or inventors located outside of Spain. Only 23% of the patents are purely domestic, with both assignees and inventors located in Spain. Therefore, the ICT innovation system in Spain seems clearly driven by its connections to foreign organizations and individuals.

The temporal evolution of patents in the ICT sector shows a positive but recent growth -Graph 1. This growth trend starts from very low levels of patenting activity in the 1970s and 80s, followed by a modest growth in the 1990s, and a significant acceleration in the 2000s. The main reason for the slow start is that Spain was immersed in a particularly serious economic crisis, throughout the seventies and the first half of the 1980s, which delayed the evolution of the sector. From 1985 to 1989, there was a significant economic recovery, which produced an impact on patent output from the beginning of the 1990s. This coincided with the integration of Spain into the European Economic Community (now European Union). European integration seems to have stimulated productive investment and the adoption of favorable measures for the renewal of equipment and techniques.

The catching-up process of Spain in the 90s also extended to the ICT sector. One of the milestones in this process was Law 12/1997, which liberalized telecommunications and anticipated the introduction of competition in the sector. A year later, Law 11/1998 established a fully liberalized regime in the provision of services and operation of telecommunications networks. From that point on, the sector has opened, allowing free competition between operators, fostering the use of technological services and the deployment of broadband. This created a fertile ground for R&D, which manifested in a significant increase in patent output. This started near the turn of the century and reached more than 300 patents per year in 2013 and 2014, a 400% increase from the mid-2000s. However, despite the impressive growth, Spain remains behind other European countries and the USA.

Graph 1. ICT patents granted associated with Spain, 1976-2014



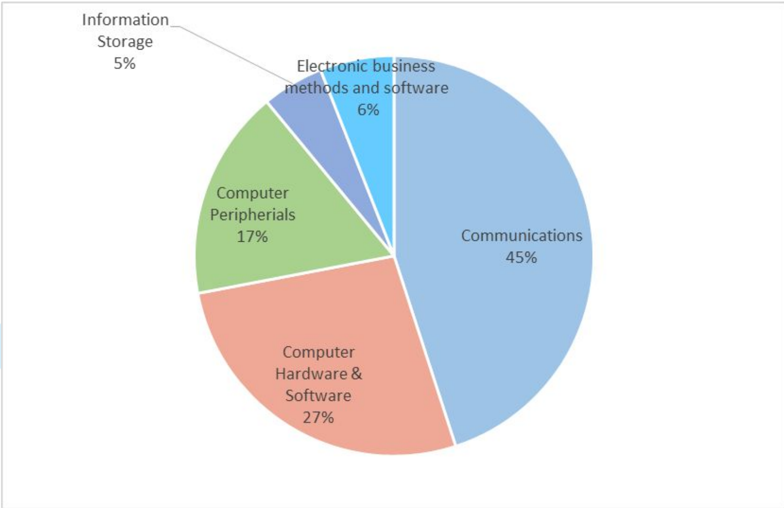
Source: Authors' own elaboration with data from the USPTO.

This lag is also reflected in the Revealed Technological Advantages Index (RTA) in ICT. RTA is an indicator of a country's relative position with respect to a particular technological field in the world. RTA is defined as the *"share of patents in a particular technology field divided by the country's share in all patent fields. The index is equal to zero when the country holds no patents in a given sector; is equal to 1 when the country's share in the sector equals its share in all fields (no specialization); and above 1 when a positive specialization is observed*". According to RTA data, the Spanish relative disadvantage is clear. The highest values in the period 1997-1999 correspond to the United States, Sweden and Japan, all with values above 1, while Spain's score (0.43) is not only much lower than the EU (0.87) and the OECD (0.82) averages, but also lower than that of emerging countries like the BRIICS (average 0.56). A decade later (2007-09), Spain had improved its score (0.62), but still lagged the aforementioned countries.

In terms of subcategories, Communications was the biggest one, representing 45% of the output (Graph 2). These patents are mainly related to the generation and/or reception of digital signals, data transmission in telecommunications networks, mobile communication devices, and procedures for determining the presence of signals in frequency bands, among others. The organizations with the largest number of patents in this subcategory are MNEs such as Bell Telephone Laboratories, Alcatel, Telefónica, Ericsson and Siemens. Most of these firms offer equipment and solutions for mobile access networks, internet protocols (IP), transmission networks and media markets around the world.

Computer Hardware and Software was the second subcategory, with 27% of the patents. A significant number of these patents relates to multicomputer data transfer and image. The third subcategory, Peripherals, represents 17% of the output; 349 patents correspond to incremental printing of symbolic information (i.e. devices and methods that can perform, under direct computer control, texts or images from individual dots created on a printing medium). The other subcategories represent less than 6%, such as Electronic Business Methods (6%), and Information Storage (5%).

Graph 2. ICT patents by technological subcategories, Spain, 1976-2014.



Source: Authors own elaboration with data from the USPTO.

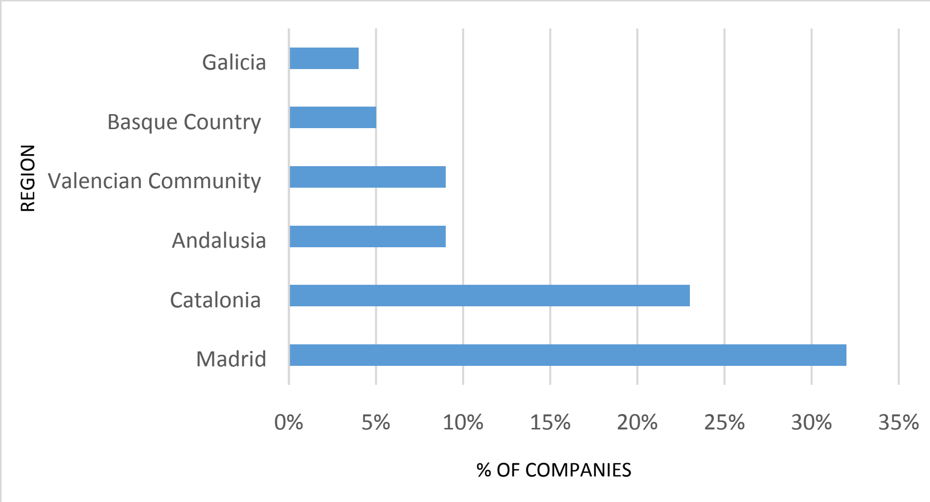
Another important consideration is the geographical distribution of inventors and organizations within Spain. While 77% of the patents are internationally connected, the rest is heavily concentrated in only three regions or "*autonomous communities*"[3]. Catalonia, Madrid and the Basque Country, in that order, account for 88% of patents associated with Spanish assignees or inventors. The remaining 12% is distributed in other regions such as Andalucía, Aragon, the Canary Islands, the Balearic Islands, Valencia and Galicia. This concentration is highly correlated with both R&D investments and the presence of companies operating in this sector that are established in these locations -Graph 3. The overall landscape of the Spanish territory is one of almost total flatness in terms of ICT innovation, interrupted by three notable spikes where activity concentrates. These three clusters of ICT innovation coincide with the three most internationally connected industrial hubs in the Spanish economy.

Although Catalonia shows relatively high patenting activity, half of its patents are linked to the Spanish company FRACTUS, S.A., a pioneer in the development of internal antennas for smartphones, tablets and the internet of things. On the other hand, MEDIA PATENTS, S.L. owns 20% of patents, and its main target is the development, programming and marketing of software and components. There are also several companies and universities such as the Polytechnic University of Catalonia and Pompeu Fabra. The second center, Madrid, produces 38% of the patents with national co-inventions, and these are linked to a handful of companies such as TELEFÓNICA of Spain, S.A., AIRBUS Operations SAS, Alcatel, y EADS Construcciones Aeronáuticas.

The regional distribution of ICT patent production follows, to a large extent, the same geographic pattern as the companies in the sector, according to other sources (Graph 3). The biggest differences are that the degree of concentration in Madrid and Catalonia is smaller, and that Basque Country (third in patent production) is number five in terms of company location. Madrid and Catalonia account for a larger share of patents than of firms, probably because the largest companies (which patent the most) are located in these regions.

[3] The administrative units of Spanish regions are called Autonomous Communities.

Graph 3. Presence of ICT companies in Spain, by regions, 2010 – 2014.



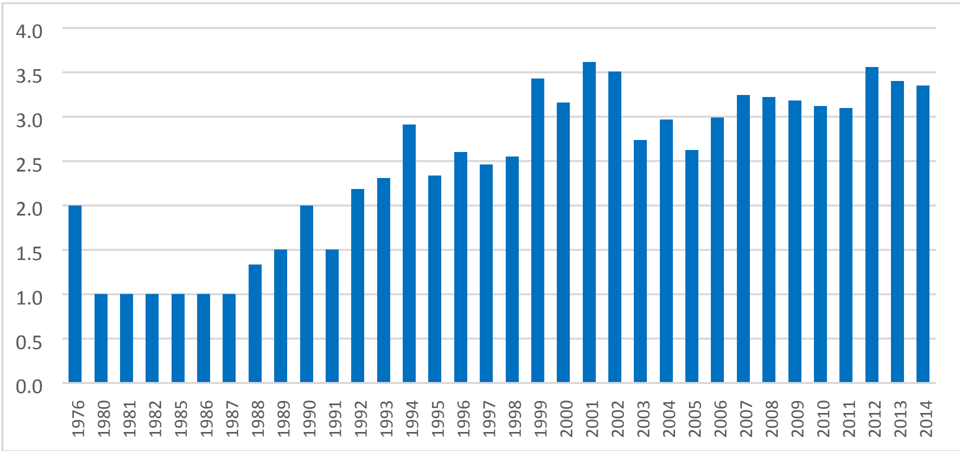
Source: ONTSI, 2016.

4.2. International collaboration on patents in the ICT sector

As described in 4.1, ICT patent production in Spain is clearly driven by connectedness to foreign pools of knowledge. Since 75.2% of patents (1,604) have one or more foreign assignees, but only 44.6% (950) have foreign inventors, the most common pattern is one of inventors located in Spain working for a company located overseas. In most cases, these inventors are employed by Spanish subsidiaries of foreign multinationals, so the patents they produce are granted to the parent company or headquarters located abroad. This reinforces the notion that peripheral regions depend, to a great extent, on the activities of MNE subsidiaries to create the linkages that will facilitate catch-up (Álvarez & Molero, 2005). This confirms what other studies in peripheral and intermediate regions of Europe have found (Berman et al., 2019).

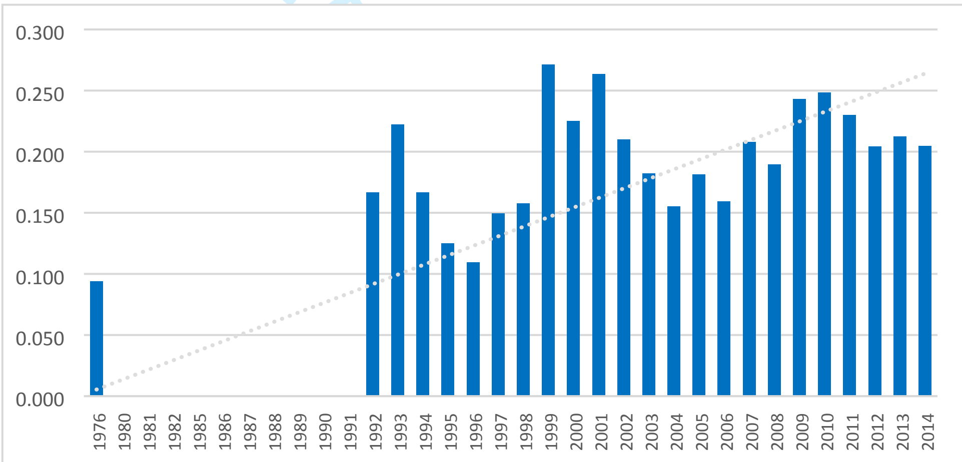
Different indicators reinforce the notion that international collaboration is driving the increase in patent production. The first indicator is the increase in the number of inventors per patent. From an average of 1 inventor per patent in the 1980s, the number grows to more than 3 in the last ten years of the dataset (Graph 4). At the same time, the percentage of Spanish inventors fell from a consistent 100% between 1977 and 1990, to as low as 48% in 1999, remaining consistently below 69%. The international dispersion of inventors, measured using the index described in section 3, shows on overall growing trend, although it peaks in the late 1990s (Graph 5). The most striking indicators of the growing geographical footprint of Spanish collaboration, however, are the number of inventor countries, both at the individual patent level, and in a given year (Graph 6). The number of inventor countries per patent went from 1 in the 1980s, to around 1.6 in the 2000s. Furthermore, the number of countries connected to Spain via co-invention rose from none in the 1980s, to nearly 30 in 2014 (Graph 6). This correlates to a large extent with the patent production growth observed in Graph 1, indicating that internationalization has acted as a leveraging mechanism for the technological performance and catching up of the Spanish ICT sector since as international collaboration grows, so does patenting.

Graph 4. Number of inventors per patent, 1976-2014



Source: Authors' own elaboration with data from the USPTO.

Graph 5. Inventor international dispersion, 1976-2014



Source: Authors' own elaboration with data from the USPTO.

With respect to country of origin of inventors, of 6,850 inventors listed for the period 1976-2014, 34% resided outside of Spain. Of those foreign inventors, more than half (51%) were located in the United States (Graph 9). Other important locations, albeit with much smaller percentages, were UK (7.3% of all foreign inventors), Germany (6.6%) and Sweden (5.9%). Other 42 countries combined accounted for 29.4%. Collaboration with European countries is favored by the EU research policy and the European Framework Program that supports numerous agreements for the improvement of technological infrastructures. Meanwhile, the global technological leadership of the U.S. in this sector is clearly reflected in the traction it generates in Spain, which in spite of being a member State of the EU, depends more heavily on connectivity to the American innovation system.

As we described in the first paragraph, the dependence of Spain on international connections is even stronger at the assignee level. Out of 2,132 assignees listed, only 497 (23.3%) were located in Spain. More than three out of four assignees were foreign. Among them, the American presence is even stronger than among inventors; 61.8% of foreign assignees were located in the U.S. Sweden (10.4%), UK (5.1%), and France (4.7%) are also significant locations (Graph 8). Other 24 countries accounted for 13.3% of the assignees. Companies from Sweden, France and

Germany include Telefonaktiebolaget LM Ericsson, European Space Agency, France Telecom, Siemens and Robert Bosch.

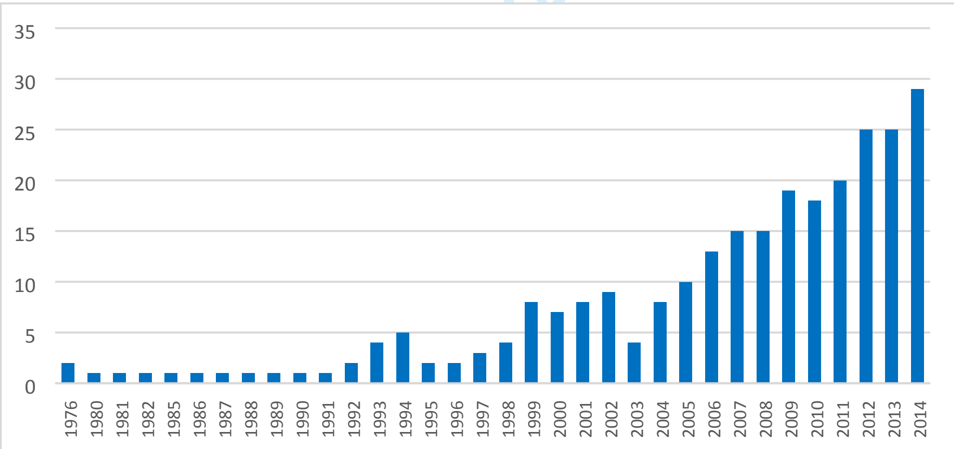
There are, however, several Spanish companies, universities, and research centers, with significant patent production. This short list of very prolific assignees includes large companies such as Telefónica of Spain, SA, Advanced Automotive Antennas, SL, Airbus Operations SAS, GMV Aerospace and Defense SA, and Marvell Hispania.

In summary, the overall picture of the ICT sector in Spain is that of a growing sector, that depends heavily on international connectivity for that growth. Those connections are mainly in the form of Spanish inventors working for companies headquartered abroad. Although the presence of foreign inventors is significant (34% of the inventors are foreign and 44.6% of the patens listed at least one foreign inventor), it is clear that the main traction comes from connectivity to foreign MNEs, since 75.2% of the patents had a foreign assignee and only 23.3% of the assignees listed were Spanish.

These results are consistent with prior literature (Álvarez and Molero, 2005) on the topic and add a more fine-grained understanding of the details and nuances of these connections. Foreign MNE subsidiaries often have higher training and R&D expenditures than domestic firms. The connection of foreign inventors to organizations established in Spain is only related to local MNE subsidiaries, like Philips Electronics, Amadeus SAS and Sony Spain, among others.

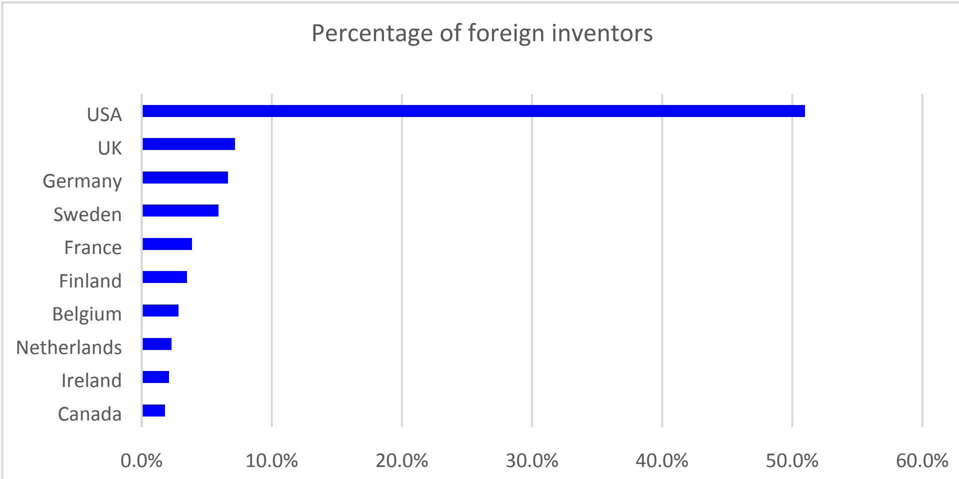
Finally, assuming that connectivity can be affected by country size, it is important to control this effect. Measuring country size by population, among the top partners of Spain in ICT patents we find large countries such as the U.S., Japan, Germany, France and UK. The presence of smaller countries like Netherlands, Sweden, Switzerland, Finland, and Ireland is explained by their high innovation capabilities, according to the Global Innovation Index (GII, 2018).

Graph 6. Total Number of Inventor Countries by year, 1976-2014



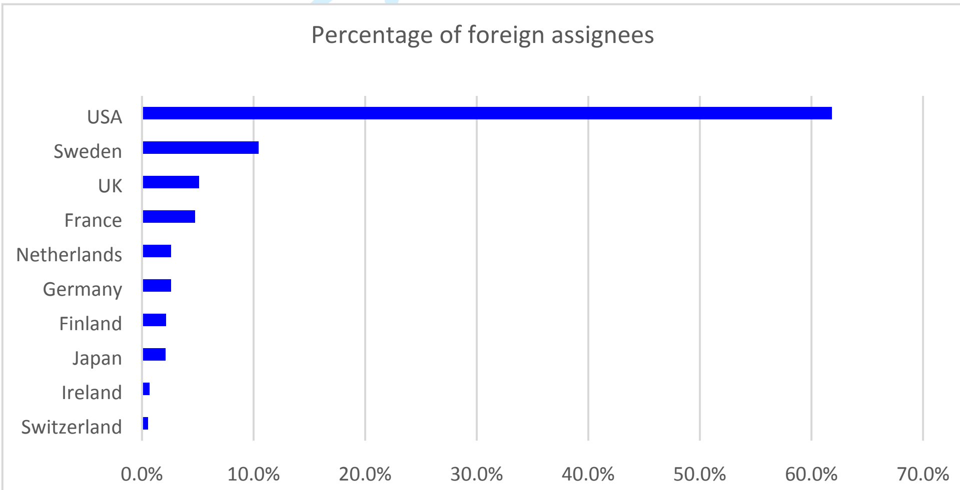
Source: Authors' own elaboration with data from the USPTO.

Graph 7. Top 10 partners of Spain, by inventors, 1976-2014



Source: Authors' own elaboration with data from the USPTO.

Graph 8. Top 10 home countries of assignees, 1976-2014



Source: Authors' own elaboration with data from the USPTO.

5. CONCLUDING REMARKS

The digital age is redefining the way we produce, consume, communicate and live. ICT does not only represent a strong sector with a high growth potential, but also one that has the most direct impact in the improvement of productivity. This, in turn, is the flywheel that fosters economic growth and the competitiveness of countries. For these reasons, governments, companies and non-profit organizations are increasingly interested in the promotion of investments and R&D oriented to the generation and use of digital technologies, an aspect that has direct consequences in the ICT sector. Moreover, in the new information and knowledge society, the vision of the world is more multicentric and multicultural, and this provides opportunities for a larger number of countries to adopt a more active role. Integration into globally dispersed value chains and international collaboration in the scientific and technological fields, are both becoming increasingly critical as countries strive to catch up with the productivity frontier and increase their living standards.

Spain has achieved significant progress in the ICT sector. The generation of patents is growing, probably stimulated (to an extent) by favorable public policies. Despite these efforts, Spain remains behind most OECD and EU countries. This creates compelling reasons to foster international collaboration as a key mechanism for catch-up.

In this paper, we analyze the importance of international connectivity in the generation of ICT knowledge in Spain, an intermediate country from the point of view of technological development. We confirm that connectivity to foreign knowledge pools and centers of excellence is critical. Additionally, we uncover the pattern of high intra-country geographical concentration, highlighting the relevance of certain regions. A few concentrated clusters of activity in Spain drive the production of ICT knowledge by acting as connecting hubs to MNEs and inventors located in more advanced countries.

The role of the United States in this process is more prominent than that of the European countries. This implies that geographical distance is not a limiting factor. This confirms the ideas of Gittelman (2007) and Hannigan et al. (2015) regarding the bimodal (either local or very distant) distribution of knowledge sourcing. Firms primarily search for knowledge in their immediate vicinity, but if necessary knowledge is not available locally, they simply seek the best possible source of knowledge elsewhere, regardless of location, instead of searching at intermediate distances. In other words, distance is a binary dimension in knowledge sourcing, not a continuous one. The connectedness of the Spanish ICT sector shows interesting patterns which confirm that moderately innovative economies rely, for the sourcing of advanced knowledge, on the connections they can establish with centers of excellence around the world.

Our findings derive implications for both managers and policy makers. In terms of public policies, they should address the development of both endogenous capabilities that would reduce the level of dependence, as well as absorptive capacities, to benefit the most from linkages with foreign agents. The deployment of resources to face the targets of the digital age also necessitates actions in the education system, with a focus on professional skills more directly related to the digitalization of tasks and productive activities, the reduction of the gender gap in the sector, and the promotion of technical studies in ICT.

Another relevant takeaway is the critical role of MNEs as conduits to acquire knowledge and foster ICT innovation. We show that the access to knowledge sources located in other latitudes is a requirement, whether through foreign inventors or through foreign firms. This, in turn, becomes key to understand the evolution of the ICT sector and its potential to contribute to the economic growth of the country. This exploratory study allows us to derive some ideas that will guide future research on international connectivity in ICT.

Finally, although the proposed approach in this research was applied to the ICT sector, the conclusions of this study are likely to extend to other sectors. Accordingly, we expect our findings to be reasonably generalizable, although with the consideration that the speed of technology change differs across technologies.

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