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Mapping innovation dynamics in the Internet of Things domain: Evidence from patent analysis

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ABSTRACT

The Internet of Things (IoT) is an emerging paradigm in the ICT sector and it is at the center of many current political and economic debates. Scholars, executives, and policymakers are becoming increasingly interested in understanding how to turn the IoT into reality, since various technological constraints (e.g., standardization and interoperability) limit the possibility of realizing an inclusive IoT information network. These constraints are exacerbated by the lack of a clear picture of the innovation dynamics and technology evolution of the IoT. This paper seeks to address this gap by mapping the development of IoT technologies. In particular, we have collected 61,972 IoT patents filed under the Patent Cooperation Treaty in the period 2000–2012. We analyze temporal trends, cross-country dynamics and identity of the applicants. Moreover, we provide insights about the development of the most relevant IoT technologies by looking at triadic patent families.

1. Introduction

In recent years, a new paradigm of information networks has emerged with the aim of expanding the scope of the services that the conventional Web usually provides, namely the Internet of Things (IoT) (Atzori et al., 2010; Feki et al., 2013; Li et al., 2015; Whitmore et al., 2015). The rationale behind the IoT recalls the logic of the Web 2.0, except for the fact that interactions and information processing occur predominantly between physical objects (household appliances, heart monitoring implants, cars, etc.) instead of between people. Accordingly, the denomination of IoT presents the two terms “Internet” and “Things”. The former reflects a network-oriented vision of communication, which entails the use of dedicated hardware, standards, and protocols, just like the Web 2.0 (Karakas, 2009); the latter tends to shift the focus to physical objects rather than to end users, as the “things” to be connected (Atzori et al., 2010). When combined, IoT semantically means a “world-wide network of interconnected objects uniquely addressable, based on standard communication protocols” (Bandyopadhyay and Sen, 2011:50).

Nowadays, the IoT is at the center of the current political and economic debates (European Commission, 2009; Li et al., 2015; OECD, 2015), since it is expected to boost new business opportunities both within and beyond the ICT sector. Some IoT applications and prototype systems have already been launched (e.g., the ZeroG Wireless, Alcatel-Lucent's Touchatag, and Arduino), revealing a growing interest in this domain (European Commission, 2009). Notwithstanding this interest, effective and large-scale systems based on the IoT paradigm are still far from being realized (OECD, 2015). This is primarily due to the technological complexity underlying IoT networks. Indeed, there are many technological issues that have to be simultaneously addressed such as standardization, interoperability, and autonomous communication (Feki et al., 2013). In addition, the fact that the implementation of IoT networks involves different types of technology controlled by multiple organizations spread across various countries (European Commission, 2014; ITU, 2005; Li et al., 2015) engenders additional complexity. Therefore, it is extremely difficult to keep pace with the technological evolution in the IoT domain, and to coordinate and “steer” standardization efforts to ensure interoperability between technological solutions and standards controlled by different and dispersed economic actors (Xu et al., 2014). Accordingly, scholars have argued that obtaining a clear picture of the innovation dynamics and technology evolution underlying the IoT is helpful for gaining valuable insights about the real meaning and functionality of the IoT (Al-Fuqaha et al., 2015:2350). There have only been a few recent studies (Al-Fuqaha et al., 2015; Bandyopadhyay and Sen, 2011; Feki et al., 2013) that have tried to represent the current state of the art of IoT solutions in order to facilitate their definition and identify future trajectories (Xu et al., 2014). Nevertheless, these works have devoted particular emphasis to the scientific theory and engineering design behind those technologies while ignoring the discussions about what technologies

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are actually available for the IoT, who has developed them, what the trends are in their development, and their potential impacts. In other words, despite the importance for social and economic growth, the development of IoT technologies has not yet received a thoughtful examination combining policy and managerial perspectives, contrary to the finer-grained analyses on its technical aspects (Whitmore et al., 2015). In line with this reasoning, this paper aims at filling these gaps by providing a comprehensive picture of the innovative efforts in the IoT domain undertaken over time at the technology, applicant and country levels. Furthermore, we complement our analyses looking at the most relevant patented innovations including insights from a policy and managerial perspective. While providing and testing a theory is beyond the scope of this paper, we provide empirical-based insights about the development of IoT technologies and a comprehensive picture of the innovative dynamics in the IoT domain at different levels of observation.

We collected all the IoT patents over the period 2000–2012 (61,972 patents) filed under the Patent Cooperation Treaty (PCT) by means of a search strategy based on the International Patent Classification (IPC) codes that best reflect patented IoT technologies (UK IP Office, 2014). Then, by leveraging bibliographic information on patents (patent application filing year, identity of the applicants, addresses of applicants, etc.), we describe their development trends looking both at the countries and the organizations mainly engaged in these innovative activities.

The paper is structured as follows. In the next section, we present a brief review of the literature on the IoT and discuss the use of patent data to analyze innovation dynamics and technology evolution. The third section presents the methods and the sample. The fourth section provides descriptive and managerial analyses on the patenting activity trends of IoT technologies. Finally, discussion, implications, and conclusion are presented in the last section.

2. Review of the literature

2.1. The Internet of Things

The logic behind the IoT finds its origin at Carnegie Mellon University in 1982 when a Coke machine was connected to the Internet, hence representing the first physical object in an Internet network.[1] Later, in the early 1990s, the idea of ubiquitous computing (Weiser, 1991) started to gain ground. This concept highlights the possibility of making everything ubiquitously connected, hence affirming the integration and automation of every object, from small household appliances to entire factories. Following this idea, in the late 1990s, the British entrepreneur Kevin Ashton coined the term IoT (Bandyopadhyay and Sen, 2011; Li et al., 2015; Ma, 2011). Although a conclusive definition has yet to be established, this acronym generally refers to a “dynamic global network infrastructure with self-configuring capabilities based on standards and interoperable communication protocols, [where] physical and virtual ‘things’ in an IoT have identities and attributes and are capable of using intelligent interfaces and being integrated as an information network” (Li et al., 2015:244; Del Giudice, 2016).

Today, the IoT paradigm is of particular interest among managers and policymakers. Indeed, projections reveal that there will be an ever-growing number of devices connected to the Internet, thus supporting the idea that a ubiquitous network of objects can engender industry disruptions and transformations (European Commission, 2014). For instance, machine-to-machine traffic is expected to account for 45% of future Internet traffic (Al-Fuqaha et al., 2015; Evans, 2011). Moreover, Gartner Inc. and ABI Research have estimated that more than 20 billion objects will be connected by 2020,[2] while a study sponsored by the McKinsey Global Institute already reported a percentage increase of 300% of online machines in recent years (Manyika et al., 2013). In turn, great social and economic benefits are expected (Bi et al., 2014; Domingo, 2012). Examples include the development of healthcare (e.g., mobile health and telecare) and manufacturing IoT applications, whose revenues are estimated to be between $1.1 and $2.5 trillion in annual growth by 2025 (Al-Fuqaha et al., 2015; Manyika et al., 2013). Consequently, almost all countries throughout the world have designed policies aimed at fostering R & D efforts in the IoT domain. Among them, some of the most relevant initiatives are the numerous cooperative projects promoted by the European Union (EU) through the IoT European Research Cluster (since 2006), the IT Reform Strategy in Japan (2009), the $800 million investment in IoT solutions by the People's Republic of China, and the allocation of a budget of £40,000,000 by the UK Government to promote IoT technology development (2015) (European Commission, 2009; Li et al., 2015; Xu et al., 2014). Furthermore, interest in the IoT domain by a relevant number of companies is revealed by the formation of the IPSO Alliance, which includes 53 firms such as the Bosch Group, SAP, Intel, and Thales, and the launch of IoT products such as ZeroG Wireless (2006), Arduino (2008), Alcatel-Lucent's Touchatag (2008), and Usman Haque's Pachube (2009) (Bi et al., 2014; European Commission, 2009).

Nevertheless, it is worth mentioning that the actual realization of a ubiquitous information network, as imagined by IoT promoters, is still in its initial stage. Indeed, relevant technological constraints do exist (Al-Fuqaha et al., 2015; Bandyopadhyay and Sen, 2011; Feki et al., 2013). These relate to the wide number of diverse technologies and protocols that are needed in order to implement the IoT paradigm and meet its three main objectives, i.e., more extensive interconnection, more intensive information perception, and more comprehensive intelligent service (Ma, 2011). Specifically, more extensive interconnection requires strong efforts in the refinement and the development of network technologies that allow managing the rising number and variety of devices that will constitute future IoT networks (Gubbi et al., 2013). In addition, in such large-scale heterogeneous networks, challenges related to efficient interconnections cannot be underestimated either, especially those requiring more reliable wireless connections (Atzori et al., 2010; Sheng et al., 2013). Instead, more intensive information perception refers to the necessity of integration and interoperability, since every device has multiple sensors, and the different devices connected together may have diverse sensors and information acquisition routines. In this case, complexity in communication is extremely severe and problems requiring effective communication control technologies emerge (e.g., non-uniformity of data, discontinuity, and inaccuracy) (Ma, 2011). Finally, more comprehensive intelligent service calls for smarter devices (Ehrenhard et al., 2014; Hong et al., 2016) that can automatically exchange and process information. However, this task is difficult without the implementation of new software modeling and data processing solutions (e.g., microcontrollers and microprocessors) that can operate in dynamic conditions (Al-Fuqaha et al., 2015).

The foregoing discussion highlights the technological complexity underlying the IoT, which is exacerbated by the presence of various actors playing different roles in this expansion phase. Indeed, the lack of a clear vision about the current state of the art of IoT technologies makes it difficult to define plans about the most promising IoT networks and to address the above-mentioned challenges. This calls for a more comprehensive picture of the innovation dynamics and technology evolution of the IoT (Bandyopadhyay and Sen, 2011).

[1] See http://www.informationweek.com/strategic-cio/executive-insights-and-innovation/internet-of-things-done-wrong-stifles-innovation/a/d-id/1279157.

[2] See https://www.abiresearch.com/press/more-than-30-billion-devices-will-wirelessly-conne/ and http://www.gartner.com/newsroom/id/3165317.

Table 1
List of IPC codes belonging to the IoT domain.

IPC code	Description
G05B019/418	Total factory control, i.e., centrally controlling a plurality of machines, e.g. direct or distributed numerical control (DNC), flexible manufacturing systems (FMS), integrated manufacturing systems (IMS), computer integrated manufacturing (CIM)
G06F015/16	Combinations of two or more digital computers each having at least an arithmetic unit, a programme unit and a register, e.g. for a simultaneous processing of several programmes
G08C017/02	Using a radio link
H04B007/26	At least one of which is mobile
H04L012/28	Characterized by path configuration, e.g. LAN [Local Area Networks] or WAN [Wide Area Networks] (wireless communication networks H04W)
H04L029/06	Characterized by a protocol
H04L029/08	Transmission control procedure, e.g. data link level control procedure
H04W004/00	Services or facilities specially adapted for wireless communication networks
H04W072/04	Wireless resource allocation
H04W084/18	Self-organising networks, e.g.; ad hoc networks or sensor networks

2.2. Innovation dynamics through patent analysis

Patent analysis is the most suitable way to analyze technological development trends and innovation dynamics (Huang et al., 2011). Several previous studies focusing on the ICT sector support this idea and corroborate our choice. For instance, Lee et al. (2016) conducted a cross-country empirical study using patent data aimed at identifying the determinants of ICT innovations. Similarly, Han and Sohn (2016) analyzed the convergence of ICT technological standards while Chang and Fan (2016) looked at the technology lifecycle of telematics. Lastly, in line with our work, the UK Intellectual Property (IP) Office (2014) first attempted to derive policy implications for the UK by examining patenting activity trends in the IoT domain.

Of course, patent analysis has some drawbacks. Indeed, not all inventions are patentable since they may not meet patentability criteria (Choi et al., 2007; Dernis et al., 2001). Moreover, firms may prefer other mechanisms to protect their technologies (e.g., secrecy) instead of patents (OECD, 2009). Besides, the value of patenting activity may change with respect to the strength of the intellectual property rights regime (Archibugi and Pianta, 1996; Choi et al., 2007) and differences do exist across countries and industries (Messeni Petruzzelli et al., 2015; Thorleuchter et al., 2010). Finally, the simple count of patents does not take into consideration the economic value of the developed technologies (Harhoff et al., 1999; OECD, 2009).

On the other hand, patenting is a common practice among innovative organizations (Comanor and Scherer, 1969; Evangelista et al., 1998; Hagedoorn and Cloodt, 2003). In addition, the requirements of novelty, originality, and non-obviousness are strongly related to the innovative activity. Finally, yet importantly, longitudinal patent data are publicly available and allow performing analysis at the level of inventor, organization, country and region (Lee et al., 2009). Scholars can then perform in-depth temporal and comparative analyses at different levels of observation (Chang and Fan, 2016; Han and Sohn, 2016; Lee et al., 2016). In addition, the technological domain(s) are clearly recognized by ad-hoc standard patent classifications (i.e., the IPC), so that sector-specific dynamics (such as IoT in this work) can be traced and insights about technology lifecycles can be highlighted (Aharonson and Schilling, 2016; Corredoira and Banerjee, 2015). Finally, patent analysis may provide useful information about the competitive and technological position of companies and countries over time (Ernst, 2001). Thereby, it may support R & D planning by helping managers and policymakers to set priorities about innovation activities (Ernst and Omland, 2011; Lee et al., 2009; Tseng et al., 2011). Eventually, despite the previously mentioned drawbacks, patents are widely used in innovation and technology management studies (e.g., Ardito et al., 2016a,b; Kim and Lee, 2015; Messeni Petruzzelli et al., 2015; Olivo et al., 2011; Thorleuchter et al., 2010).

3. Methods

3.1. Data collection

Our analysis of the IoT patent landscape hinges on patent data extracted from the OECD REGPAT database (February 2016 version) (Maraut et al., 2008). The REGPAT database comprises patent applications filed under the PCT. For each patent, it provides information about the geographical location of applicants and inventors and about the IPC classes the patent belongs to. In particular, we focus on the PCT applications in order to reduce potential biases, e.g., “home” advantage bias, with regard to applications filed under regional/country patent offices. Moreover, the PCT is considered the most favorable way to patent an invention into multiple countries/offices (Grupp and Schmoch, 1999).

In order to identify patents in the IoT domain, we adopted a search strategy based on the IPC codes most related to the IoT. In doing so, we referred to the IPC classification proposed by the UK IP Office (UK IP Office, 2014). Accordingly, we classified a patent as belonging to the IoT domain if at least one of its IPC codes is included in the list in Table 1 (UK IP Office, 2014). Specifically, we looked at patents with application year ranging between 2000, the year when the concept of IoT started to emerge (Li et al., 2015), and 2012. We limit our analysis to 2012 because we observed a severe drop in the number of patents applied for after 2012, most likely caused by the lengthy duration of a patent's examination process. Therefore, we exclude patents with application year after 2012 because their count is not reliable. This procedure yielded a final sample of 61,972 IoT patent applications, representing 3.28% of the 1,891,756 patent applications in the REGPAT database in the time span 2000–2012.

Starting from these 61,972 patent applications classified as IoT, we categorize them into different IoT subclasses, with the aim of offering fine-grained information about the IoT technological development. In fact, as explained in Section 2, the realization of a ubiquitous IoT network lies in the co-evolution of many technological areas. Specifically, we followed prior literature about IoT (see Section 2) and analyzed the IPC codes that best describe the different technologies pertaining to the IoT (UK IP Office, 2014) in order to identify the main technological subclasses. Then, we asked academic experts in the field of IoT to evaluate our classification in terms of clarity, specificity, and representativeness. By considering the experts' feedback and advice, we finally identified four technological categories: Network systems technologies (belonging to H04L12/28, H04W84/18 and H04W4/00 classes), Communication control technologies (H04L29/08, H04L29/06 and G05B19/418), Wireless transmission technologies (G08C17/02, H04B7/26 and H04W72/04) and Data processing technologies (G06F15/16).

Table 2
PCT applications and triadic patent families by applicant location (2000–2012).

		PCT										TPF				
		PCT applications in IoT		PCT applications (all)		Specialization	Co-patenting		International co-patenting			TPF in IoT		TPF (all)		Specialization
Rank	Country	Tot. share	Col %	Tot. share	Col %	Norm. BI	% in IoT	% (all)	% in IoT	% (all)	Rank (TPF)	Tot. share	Col %	Tot. share	Col %	Norm. BI
1	United States of America	22,862	36.89	600,266	31.73	0.075	3.68	7.24	1.54	2.62	1	12,509	36.63	181,553	28.21	0.130
2	China	7137	11.52	87,669	4.63	0.426	3.47	11.38	1.20	2.61	5	1400	4.10	7604	1.18	0.553
3	Japan	6581	10.62	344,451	18.21	− 0.263	5.08	9.43	2.03	1.42	2	9177	26.87	206,205	32.04	− 0.088
4	Republic of Korea	5638	9.10	81,524	4.31	0.357	5.63	10.68	1.09	1.71	3	2461	7.21	24,098	3.74	0.316
5	Sweden	3472	5.60	41,963	2.22	0.433	0.86	4.25	0.63	2.22	7	1196	3.50	10,099	1.57	0.381
6	Finland	3299	5.32	23,871	1.26	0.617	1.66	3.27	1.06	1.56	10	674	1.97	3771	0.59	0.542
7	France	2987	4.82	82,368	4.35	0.051	3.80	17.64	2.44	9.43	4	1463	4.28	31,650	4.92	− 0.069
8	Germany	2802	4.52	211,846	11.20	− 0.425	8.49	8.49	6.49	4.90	6	1295	3.79	68,844	10.70	− 0.477
9	Canada	1377	2.22	30,298	1.60	0.162	6.35	13.50	2.45	6.66	11	626	1.83	6589	1.02	0.283
10	Netherlands	1211	1.95	53,538	2.83	− 0.183	13.94	20.85	10.90	19.16	8	981	2.87	21,317	3.31	− 0.071
11	United Kingdom	1181	1.91	64,184	3.39	− 0.281	6.30	14.22	4.56	9.79	9	686	2.01	18,846	2.93	− 0.186
12	Israel	559	0.90	18,376	0.97	− 0.037	9.12	12.40	4.04	4.02	13	205	0.60	3959	0.62	− 0.011
13	Switzerland	457	0.74	46,220	2.44	− 0.536	7.42	15.29	6.36	13.88	14	135	0.39	14,490	2.25	− 0.702
14	Italy	319	0.52	31,654	1.67	− 0.529	8.02	10.33	3.09	3.39	15	134	0.39	8674	1.35	− 0.550
15	Australia	259	0.42	22,507	1.19	− 0.481	7.60	10.58	3.42	3.37	17	117	0.34	4362	0.68	− 0.330
16	Singapore	199	0.32	6805	0.36	− 0.056	8.29	12.90	5.37	7.46	19	70	0.21	1350	0.21	− 0.010
17	Ireland	188	0.30	5530	0.29	0.019	3.68	11.46	1.58	7.59	22	50	0.15	963	0.15	− 0.013
18	Spain	174	0.28	15,455	0.82	− 0.490	13.19	17.64	8.79	4.30	20	70	0.21	2518	0.39	− 0.312
19	India	168	0.27	11,474	0.61	− 0.382	18.02	14.42	4.07	5.39	16	122	0.36	2183	0.34	0.027
20	Norway	101	0.16	7647	0.40	− 0.424	2.97	7.48	0.99	3.74	25	35	0.10	1364	0.21	− 0.344
21	Cayman Islands	98	0.16	1397	0.07	0.361	5.94	9.46	5.94	9.39	26	34	0.10	221	0.03	0.487
22	Malaysia	92	0.15	1950	0.10	0.178	5.38	12.32	3.23	7.54	44	4	0.01	207	0.03	− 0.442
23	Luxembourg	86	0.14	3343	0.18	− 0.118	3.41	7.57	3.41	7.11	32	13	0.04	454	0.07	− 0.313
24	Denmark	81	0.13	14,735	0.78	− 0.713	4.94	8.39	2.47	4.65	21	62	0.18	3523	0.55	− 0.504
25	Barbados	71	0.11	2643	0.14	− 0.102	1.41	2.46	1.41	2.42	24	35	0.10	172	0.03	0.590

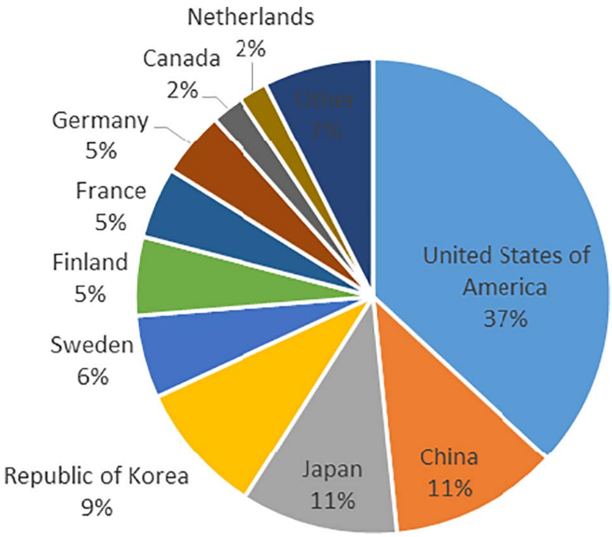


Fig. 1. Shares of Internet of Things PCT applications by country (2000 – 2012).

3.2. Methodological approach

In this section, we explain the methodological approach at the basis of our analysis and present the main measures and their underlying rationale.

3.2.1. Country-level analysis

In our analysis, we tracked patent applications in time by using the application year instead of the granting year. Since the granting process usually takes a long time, the application year is closer to the point in time when the invention is developed (Albino et al., 2014). Instead, in order to assign a patent application to a country, we used the location of the applicants[3] and we computed the sum of the fractional count[4] of applications for each country (de Rassenfosse et al., 2013).

As a proxy for the extent to which companies and organizations in a given country collaborate in developing patents, we calculated the percentage of patent applications with multiple applicants. The relevance of this aspect lies in the need to understand collaborative dynamics in order to better understand and improve inventive and innovation activities (Sampson, 2007). We computed an analogous index, namely, international co-patenting, that is the percentage of patent applications in a certain country with at least one applicant located abroad.

We also aim at understanding the relative specialization of a country in the IoT domain with respect to other technologies/sectors within the same country and with respect to other countries. Thus, we computed a relative measure of the weight of IoT in the patent portfolio of a country. In order to understand the level of specialization in IoT for a country, we used a normalized Balassa index (BI). For dimension k (e.g. a time span), let ${N_{i,j}}^k$ be the number of patents that belongs to category j (i.e., "IoT") made by i (e.g. country X). The BI is defined as follows:

$$BI_{i,j}^{k} = \frac{N_{i,j}^{k}}{\sum_{j} N_{i,j}^{k}} \cdot \left(\frac{\sum_{i} N_{i,j}^{k}}{\sum_{i,j} N_{i,j}^{k}} \right)^{-1}$$

The BI is easy to compute and has an intuitive interpretation but also has some shortcomings, i.e., it tends to have an asymmetric and skewed distribution (Dalum et al., 1998). In order to alleviate these problems and to have an index with a fixed scale over time, we computed a symmetric version of the BI by applying the following transformation proposed by Dalum et al. (1998):

$$TBI_{i,j}^{k} = \frac{BI_{i,j}^{k} - 1}{BI_{i,j}^{k} + 1}$$

The resulting index will be in the range $[-1; +1]$, with values above zero pointing to a positive specialization in IoT for a certain country, while values below zero indicating that the country is negatively specialized. Please note that we computed the same specialization indexes for IoT technological subclasses. However, in that analysis, the relative specialization of a subclass, e.g., Wireless technologies, is computed with respect to only the IoT patents and not with respect to the entire patent portfolio of a country. Therefore, we interpreted that measure as a specialization index within the IoT domain.

Finally, since we attempt to identify the most relevant IoT patents in terms of economic and technological impact, we replicated our analysis focusing on triadic patent families (TPF) reported in the TPF database[5] (February 2016 version). TPF are defined by the OECD as a set of patents taken at the EPO, JPO and USPTO that share one or more priorities (Dernis and Khan, 2004). Indeed, TPF are considered more significant than conventional patents since they usually have a greater relevance in the global market, they are more frequently commercialized, and they refer to inventions characterized by better technological performances (Walsh et al., 2016). In regards to TPF, we identified 34,151 (5.31%) IoT families out of 643,523 total families in the period 2000–2012. We also categorized them according to our technological classification of IoT solutions (see the previous section).

3.2.2. Applicant-level analysis

Besides the country-level analysis, we performed an analysis looking at the identity of the main applicants (top 20) in the IoT domain in the world. This analysis identifies the single organizations involved in the development of IoT solutions in order to highlight "who" is mainly responsible for the development of these technologies (see the paper by Albino et al. (2014) for an example in the green energy field). In order to do so, we homogenized names of the applicants and computed the sum of the fractional count of patent applications. In addition to the simple count, we calculated the percentage of IoT patents with respect to the IoT domain (column named "col %") and the percentage of IoT patents with respect to the patent portfolio of the applicant itself (column named "applicant %").

4. Results

4.1. The overall IoT landscape

In this section, we will start by observing the panorama of the IoT patent landscape and performing country-level and applicant-level analyses. We will then focus on the different categories of the IoT, namely Network systems technologies, Communication control technologies, Wireless transmissions technologies, and Data processing technologies, as defined above.

[3] Alternatively, we reproduced the analysis using inventor location instead. The results were analogous to the one using applicant location; they are available from the authors upon request.

[4] Fractional counts are applied for patents with multiple inventors/applicants: when a patent is assigned to multiple applicants from different countries/regions, the respective contributions of each country/region is taken into account. For example, if an application has 2 applicants from different countries, each country is assigned a fractional count of 0.5.

[5] For a detailed description of the OECD REGPAT database and the OECD Triadic Patent Families database see Dernis and Khan (2004).

(a) shares of PCT applications

(b) shares of Triadic Patent Families

(c) specialization based on PCT applications (normalized Balassa index)

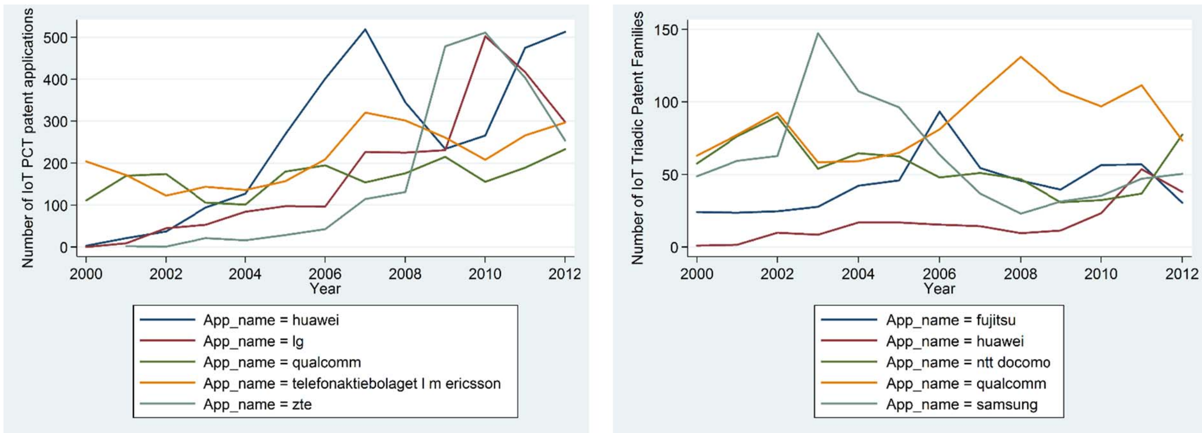
(d) specialization based on TPF (normalized Balassa index)

Fig. 2. Evolution of patent applications and specialization from 2000 to 2012 of top 5 countries in IoT.

In Table 2, we report the fractional count of patent applications and triadic patent families by country for the period 2000–2012. First of all, the United States of America (USA) ranks first both in terms of PCT (applications) and TPF (families), as it is responsible for more than one third of them (36.9% and 36.6% respectively). In other words, the USA represents the leading country in the development of IoT technologies both in terms of mere count and quality-weighted count. The USA is followed by China, Japan, and the Republic of Korea, with percentages

Table 3
Main applicants in the IoT in terms of PCT applications and triadic patent families.

PCT					TPF				
Rank	Applicant name	PCT applications in IoT	Col %	Applicant %	Rank	Applicant name	TPF in IoT	Col %	Applicant %
1	Huawei	3304	5.33	21.50	1	Qualcomm	1124	3.11	40.30
2	Telefonaktiebolaget L M Ericsson	2797	4.51	24.48	2	Samsung	810	2.24	18.45
3	Nokia	2499	4.03	25.81	3	NTT DoCoMo	728	2.01	52.56
4	LG	2285	3.69	23.78	4	NEC	641	1.77	25.72
5	Qualcomm	2159	3.48	15.88	5	Koninklijke Philips N V	601	1.66	6.21
6	ZTE	2004	3.23	15.67	6	Microsoft	582	1.61	29.10
7	Samsung	1652	2.67	22.59	7	Fujitsu	565	1.56	16.51
8	Intel	995	1.60	12.41	8	Sony	434	1.20	10.17
9	Siemens	936	1.51	6.71	9	Telefonaktiebolaget L M Ericsson	413	1.14	46.92
10	Koninklijke Philips N V	881	1.42	4.30	10	LG	352	0.97	20.89
11	Alcatel Lucent	878	1.42	24.35	11	Nokia	332	0.92	43.87
12	Panasonic	797	1.29	4.53	12	Matsushita Electric Industrial	331	0.92	9.77
13	NTT DoCoMo	756	1.22	30.09	13	Alcatel Lucent	301	0.83	48.23
14	Microsoft Licensing LLC	713	1.15	20.35	14	Panasonic	235	0.65	11.36
15	Motorola	701	1.13	17.53	15	RCA Thomson Licensing	227	0.63	16.99
16	Intellectual business machines	697	1.12	11.71	16	Huawei	221	0.61	47.00
17	Cisco	688	1.11	36.26	17	International Business Machines	220	0.61	19.73
18	NEC	616	0.99	7.01	18	Lucent	197	0.54	33.00
19	Fujitsu	556	0.90	8.74	19	Interdigital	191	0.53	62.81
20	Hewlett Packard Development LP	512	0.83	9.32	20	Toshiba	187	0.52	8.36



(a) share of PCT applications (b) share of Triadic Patent Families

Fig. 3. Evolution of PCT patent applications and triadic patent families from 2000 to 2012 of the top 5 applicant in IoT in 2012.

around 10% for PCT (11.5%, 10.6% and 9.1%, respectively) although Japan has a much higher percentage when looking at TPF (26.8%), while China drops at 4.1%. According to these findings, it is interesting to note that the patenting activity of China and the Republic of Korea surpasses that of European countries. As showed also in Fig. 1, those first four countries account for around 65% of the total number of patents, and they are followed by several European countries and Canada, with percentages around 5%.

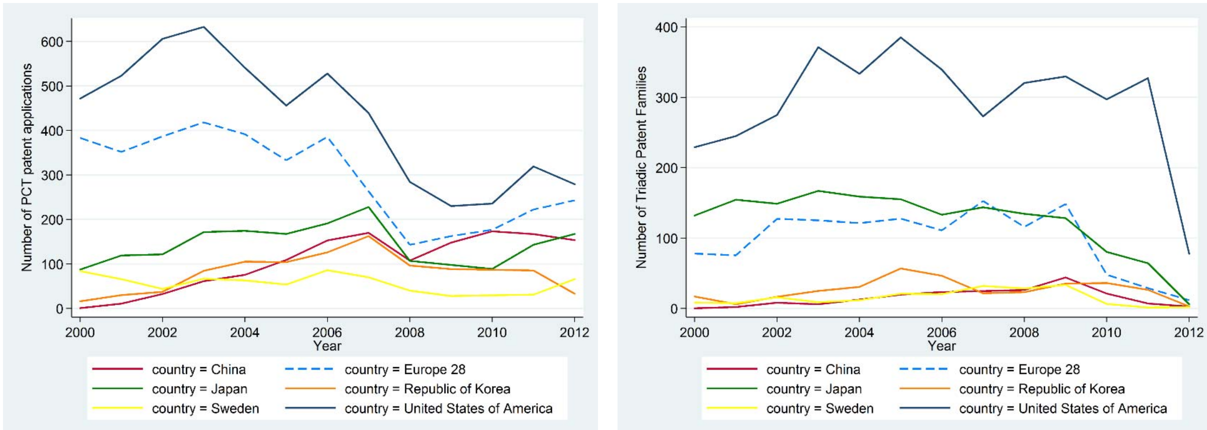
Looking at the co-patenting rate, we can see that the percentage of IoT patents with multiple applicants is 17.7% on average, generally lower than the overall average of 27.9%. This evidence seems to be even stronger for high-ranked countries, with percentages that are nearly half. Moreover, Table 2 reveals that international cooperation is limited in all the countries especially when looking at the IoT domain. In fact, the percentage of patents with foreign applicants is 11.2% in IoT, while it is 20.5% overall. The most patent intensive countries (i.e., the USA, China, and Japan) are characterized by low rates of international collaboration, as compared to the European ones. This may suggest that knowledge about IoT technologies tends to be nationally bounded more than in other domains.

Fig. 2(a) and (b) present the evolution in time of the amount of patents, confirming the findings in Table 1 in regards to the country-level analysis. In particular, Europe ranks third in both PCT applications and TPF. However, especially in PCT, China has made giant leaps ahead of Europe from 2011 due to a sizeable growth in recent years.

As previously described, we also computed the normalized Balassa Index in order to understand the relative country specialization in the IoT. In Table 2 and Fig. 2(c) and (d), we highlight that some countries are relatively more specialized in the IoT, i.e., China, the Republic of Korea and Sweden, while Japan is negatively specialized, and the USA is not characterized by a strong relative specialization, even though it ranks first in the total number of IoT patents. In particular, it is worth mentioning that China is the most specialized country, hence suggesting that a large part of its overall innovative efforts are directed toward the IoT and, more in general, the ICT sector. These patterns of specialization are rather stable in time with the exception of China, which

Table 4
Network systems technologies: PCT applications and triadic patent families by applicant location (2000–2012).

		PCT applications		Specialization			TPF		Specialization
Rank	Country	Tot. share	Col %	Norm. BI	Rank	Country	Tot. share	Col %	Norm. BI
1	United States of America	5546	37.63	0.010	1	United States of America	4658	35.66	− 0.013
2	Japan	1865	12.65	0.087	2	Japan	3274	25.07	− 0.035
3	China	1363	9.25	− 0.109	3	Republic of Korea	1086	8.32	0.072
4	Republic of Korea	1057	7.17	− 0.119	4	France	560	4.29	0.001
5	Finland	848	5.75	0.039	5	Germany	520	3.98	0.025
6	Sweden	729	4.94	− 0.063	6	China	512	3.92	− 0.022
7	France	680	4.61	− 0.022	7	Sweden	501	3.83	0.045
8	Germany	597	4.05	− 0.055	8	Netherlands	472	3.61	0.114
9	Netherlands	550	3.73	0.312	9	Canada	301	2.31	0.114
10	Canada	489	3.32	0.198	10	Finland	276	2.11	0.034
11	United Kingdom	243	1.65	− 0.072	11	United Kingdom	259	1.98	− 0.007
12	Israel	138	0.94	0.018	12	Taiwan, Province of China	117	0.90	0.123
13	Italy	80	0.54	0.023	13	Israel	83	0.63	0.026
14	Switzerland	74	0.50	− 0.190	14	Italy	49	0.37	− 0.024
15	Singapore	61	0.41	0.121	15	India	45	0.35	− 0.017
16	Australia	56	0.38	− 0.049	16	Australia	36	0.27	− 0.112
17	India	43	0.29	0.033	17	Switzerland	34	0.26	− 0.206
18	Spain	38	0.26	− 0.037	18	Singapore	34	0.26	0.111
19	Malaysia	35	0.24	0.233	19	Belgium	33	0.25	− 0.014
20	Norway	25	0.17	0.018	20	Denmark	27	0.21	0.069
21	Luxembourg	23	0.16	0.057	21	Spain	23	0.18	− 0.067
22	Ireland	21	0.14	− 0.362	22	Barbados	17	0.13	0.126
23	Denmark	21	0.14	0.031	23	Austria	17	0.13	− 0.022
24	Barbados	17	0.12	0.007	24	Hungary	17	0.13	0.169
25	Russian Federation	15	0.10	− 0.044	25	Ireland	16	0.12	− 0.099



(a) share of PCT applications (b) share of Triadic Patent Families

Fig. 4. Evolution of PCT patent applications and triadic patent families from 2000 to 2012 of top 5 countries in network systems technologies.

switched to a positive index in the early 2000s, and Japan, whose specialization in the IoT has steadily decreased.

In Table 3 and Fig. 3, we also analyze the main patent applicants. At the top of PCT and TPF rankings we find major players in mobile telecommunications (Huawei, Samsung, Ericsson, Nokia, LG, ZTE, and NTT docomo), wireless telecommunications (Qualcomm), and hardware and software companies (Intel, Microsoft, Fujitsu, and Sony). The main applicants are mainly from the USA, China, and Japan, reflecting the trends we described at the country-level.

4.2. Network systems technologies

In Table 4, we replicate the analysis of Table 2, but looking only at the Network system technology subclass. Top positions appear to be similar to IoT as a whole: the USA stands steadily first, with Japan, China, and the Republic of Korea following. A similar pattern is present for TPF and, like the IoT as a whole, Japan's TPF rises while China's shrinks. Moreover, it seems that there are no major differences in terms of specialization, since most of the countries have a normalized BI close to zero. The only exceptions are the Netherlands and Ireland. The first is positively specialized in Network systems, while the second presents a negative BI. Please note that specialization indexes reported here are with respect to IoT patents. In Fig. 4, we see that countries' rankings are rather stable over time, with the USA and Europe leading and with Japan and China following, in terms of number of applications.

Table 5 reports the main applicants in Network systems technology. Among others, it is interesting to note that Philips is rather focused on network systems, as slightly more than 50% of its patents lie in this class.

4.3. Communication control technologies

Table 6 presents country statistics in Communication control technologies. The USA still leads the ranking followed by China in PCT applications and Japan in TPF. The only significant change is the Republic of Korea, whose BI points to the negative specialization in this particular subclass. More precisely, Fig. 5 shows an interesting pattern in time: the USA decreased its yearly production rate of Communication control PCT applications over our period of analysis, while China has steadily grown, becoming the first country in 2012 followed by Europe and the USA. However, this pattern is different when looking at TPF, with the USA followed by Japan and Europe. Previously mentioned evidences are consistent at the applicant level, with the prevalence of Chinese and European companies (Huawei and ZTE, and Ericsson and

Table 5
Main applicants in network systems technologies in terms of PCT applications and triadic patent families.

PCT rank	Applicant name	PCT applications	Col %	Applicant %	TPF Rank	Applicant name	TPF	Col %	Applicant %
1	Nokia	720	8.20	28.79	1	Qualcomm	462	11.25	41.10
2	Huawei	702	7.99	21.23	2	Samsung	393	9.56	48.51
3	Telefonaktiebolaget L M Ericsson	553	6.30	19.77	3	Koninklijke Philips N V	308	7.49	51.21
4	Qualcomm	537	6.12	24.87	4	Ntt DoCoMo	241	5.87	33.10
5	Koninklijke Philips N V	462	5.27	52.47	5	NEC	215	5.24	33.61
6	Samsung	372	4.23	22.48	6	Fujitsu	194	4.73	34.34
7	ZTE	339	3.87	16.94	7	Telefonaktiebolaget L M Ericsson	180	4.38	43.55
8	Intel	310	3.53	31.14	8	Sony	154	3.75	35.48
9	Motorola	278	3.17	39.71	9	Nokia	133	3.23	39.90
10	LG	275	3.13	12.04	10	Alcatel Lucent	117	2.85	38.98
11	Panasonic	257	2.92	32.18	11	LG	116	2.83	32.95
12	Cisco	228	2.60	33.20	12	RCA Thomson Licensing	114	2.77	50.18
13	Thomson Licensing	226	2.57	44.36	13	Microsoft	111	2.71	19.14
14	Siemens	224	2.55	23.88	14	Panasonic	111	2.71	47.41
15	Fujitsu	190	2.16	34.12	15	Interdigital	99	2.40	51.56
16	NEC	183	2.08	29.61	16	Matsushita Electric Industrial	87	2.12	26.31
17	Sony	174	1.98	37.43	17	Toshiba	73	1.79	39.26
18	Interdigital	151	1.72	50.08	18	Lucent	68	1.66	34.67
19	Alcatel Lucent	143	1.63	16.33	19	Huawei	68	1.65	30.77
20	NTT DoCoMo	140	1.59	18.44	20	Canon	65	1.59	34.95

Table 6
Communication control technologies: PCT applications and triadic patent families by applicant location (2000–2012).

		PCT applications		Specialization			TPF		Specialization
Rank	Country	Tot. share	Col %	Norm. BI	Rank	Country	Tot. share	Col %	Norm. BI
1	United States of America	11,942	36.03	− 0.012	1	United States of America	5199	38.58	0.026
2	China	4556	13.75	0.088	2	Japan	3280	24.34	− 0.049
3	Sweden	2459	7.42	0.139	3	France	741	5.50	0.125
4	Japan	2303	6.95	− 0.209	4	Republic of Korea	708	5.25	− 0.157
5	France	2251	6.79	0.170	5	Germany	607	4.51	0.086
6	Finland	2162	6.52	0.101	6	China	495	3.67	− 0.055
7	Germany	2079	6.27	0.162	7	Sweden	481	3.57	0.010
8	Republic of Korea	986	2.98	− 0.507	8	Netherlands	365	2.71	− 0.029
9	United Kingdom	898	2.71	0.174	9	Finland	334	2.48	0.113
10	Canada	770	2.32	0.022	10	United Kingdom	264	1.96	− 0.012
11	Netherlands	604	1.82	− 0.035	11	Canada	233	1.73	− 0.030
12	Switzerland	370	1.11	0.203	12	Israel	98	0.73	0.096
13	Israel	295	0.89	− 0.007	13	Taiwan, Province of China	68	0.50	− 0.164
14	Italy	204	0.61	0.088	14	Switzerland	67	0.50	0.118
15	Ireland	164	0.49	0.239	15	Italy	67	0.49	0.117
16	Spain	124	0.37	0.142	16	Belgium	58	0.43	0.248
17	Australia	119	0.36	− 0.074	17	Australia	54	0.40	0.084
18	Singapore	108	0.33	0.008	18	India	54	0.40	0.059
19	India	82	0.25	− 0.044	19	Spain	43	0.32	0.220
20	Norway	79	0.24	0.186	20	Singapore	26	0.19	− 0.032
21	Luxembourg	56	0.17	0.095	21	Ireland	24	0.18	0.104
22	Cayman Islands	55	0.16	0.022	22	Denmark	23	0.17	− 0.024
23	Denmark	53	0.16	0.096	23	Cayman Islands	20	0.15	0.207
24	Austria	42	0.13	0.179	24	Norway	17	0.13	0.110
25	Belgium	41	0.12	0.244	25	Austria	17	0.13	− 0.046

Nokia, respectively) in the PCT ranking, while Qualcomm and Microsoft lead in terms of the number of TPF, as shown in Table 7.

4.4. Wireless transmission technologies

Table 8 reports figures about Wireless transmission technologies. According to the table, the Republic of Korea and Japan, followed by the USA and China, are responsible for most of the PCT applications in this subclass. Japan is leading also in the TPF ranking, while the USA is a close follower. It is interesting to note the high level of specialization of the Republic of Korea and Japan with respect to (almost) all other countries, thus revealing their strong innovative efforts in this particular technology field of the IoT domain. In Fig. 6(a) and (b), the rise of the Republic of Korea is evident, since it has started leading in terms of PCT application from 2007.

Given the previous mentioned result, it is not surprisingly that LG and Samsung stand out. In fact, the former is responsible for 17% of the world PCT applications in Wireless transmission technologies (Table 9).

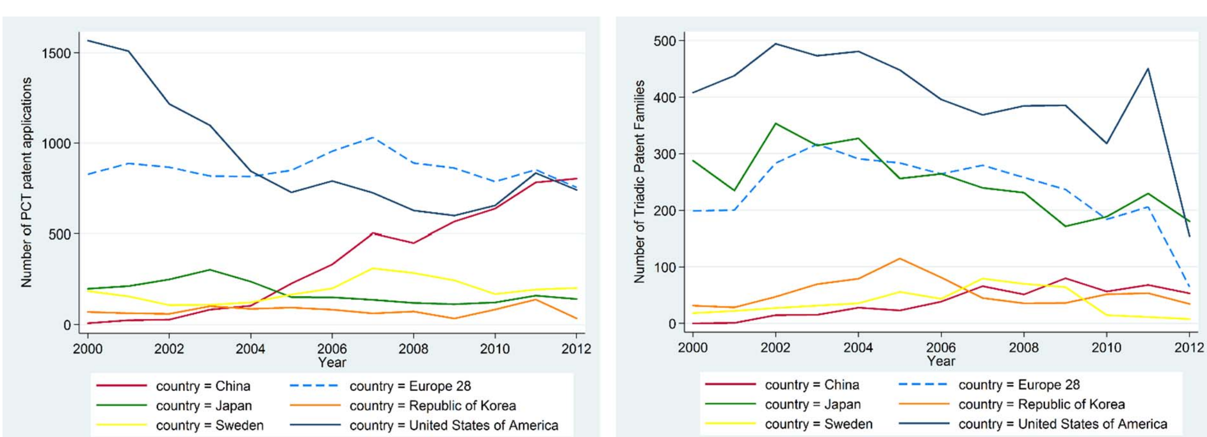
4.5. Data processing technologies

Table 10 and Fig. 7(a) and (b) show the striking dominance of the USA in the Data processing technologies subclass. In fact, it is responsible for 78% of PCT applications and 49% of TPF. This fact is also reflected by the high positive degree of specialization within the IoT domain, as compared to (almost) all other countries. Notable exceptions are Israel, Australia, and India that climbed up the chart in this specific subclass.

Looking at the main applicants in Table 11, four out of the top five and eight out of the top ten are USA-based companies in the number of PCT applications. In particular, in this subclass there is a prevalence of American software and hardware companies such as Microsoft, HP, Intel, Google, and CISCO.

5. Discussion and conclusions

This article examines the innovation dynamics in the IoT domain.



(c) share of PCT applications (d) share of Triadic Patent Families

Fig. 5. Evolution of PCT patent applications and triadic patent families from 2000 to 2012 of top 5 countries in communication control technologies.

Table 7
Main applicants in communication control technologies in terms of PCT applications and triadic patent families.

PCT rank	Applicant name	PCT applications	Col %	Applicant %	TPF Rank	Applicant name	TPF	Col %	Applicant %
1	Huawei	2145	6.47	64.94	1	Qualcomm	320	2.20	28.48
2	Telefonaktiebolaget L M Ericsson	1945	5.87	69.54	2	Microsoft	287	1.98	49.41
3	Nokia	1659	5.00	66.38	3	Samsung	254	1.74	31.33
4	ZTE	1260	3.80	62.87	4	Koninklijke Philips N V	205	1.41	34.07
5	Qualcomm	1043	3.15	48.29	5	Sony	204	1.41	47.13
6	Siemens	699	2.11	74.68	6	Nokia	180	1.24	54.23
7	Alcatel Lucent	628	1.89	71.52	7	NEC	175	1.20	27.25
8	Intellectual Business Machines	554	1.67	79.42	8	NTT DoCoMo	174	1.20	23.94
9	Cisco	477	1.44	69.28	9	Fujitsu	167	1.15	29.45
10	Koninklijke Philips N V	384	1.16	43.55	10	Telefonaktiebolaget L M Ericsson	166	1.14	40.33
11	Intel	348	1.05	35.01	11	International Business Machines	144	0.99	65.35
12	Samsung	343	1.03	20.73	12	RCA Thomson Licensing	134	0.92	58.94
13	Nokia Siemens Networks & KG	336	1.01	70.22	13	Alcatel Lucent	133	0.91	44.19
14	Thomson Licensing	333	1.00	65.48	14	Matsushita Electric Industrial	125	0.86	37.82
15	Microsoft Licensing LLC	310	0.94	43.48	15	Hitachi	115	0.79	61.76
16	Panasonic	265	0.80	33.24	16	Canon	97	0.67	51.93
17	Motorola	257	0.77	36.62	17	LG	89	0.61	25.12
18	Tencent (Shenzhen)	255	0.77	86.71	18	Huawei	88	0.60	39.85
19	Orange	251	0.76	84.51	19	Toshiba	87	0.60	46.51
20	France Telecom	248	0.75	87.92	20	Panasonic	72	0.49	30.46

Since the late 1990s, the IoT paradigm has captured the attention of scholars, executives, and policymakers given its touted potential for improving existing information networks and providing relevant economic and social benefits (Bi et al., 2014; Domingo, 2012).

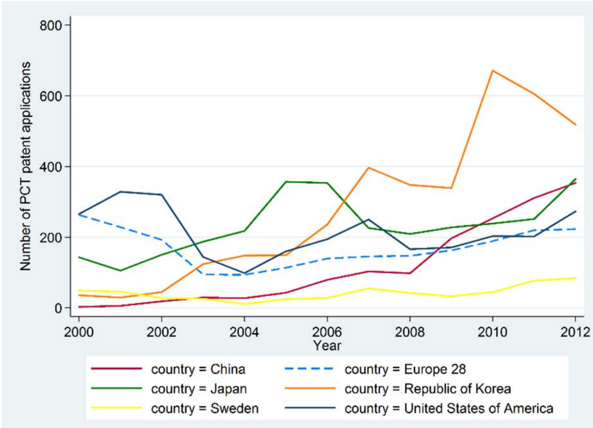
In this paper, we provide a comprehensive overview of the patenting activity trends in the IoT domain at the technology, applicant, and country levels. Using the REGPAT database, we collected a set of 61,972 IoT patents filed under the Patent Cooperation Treaty between 2000 and 2012. We categorize these patents into four main technological fields, namely Network systems technologies, Communication control technologies, Wireless transmission technologies, and Data processing technologies. Disentangling the amount of patents into these technological fields has allowed us to conduct an in-depth analysis of the technology-related activities in the IoT domain. Using patents as a measure of the innovative efforts undertaken by countries and organizations, our findings provide relevant theoretical, managerial, and policy implications related to the IoT domain.

5.1. Theoretical, managerial, and policy implications

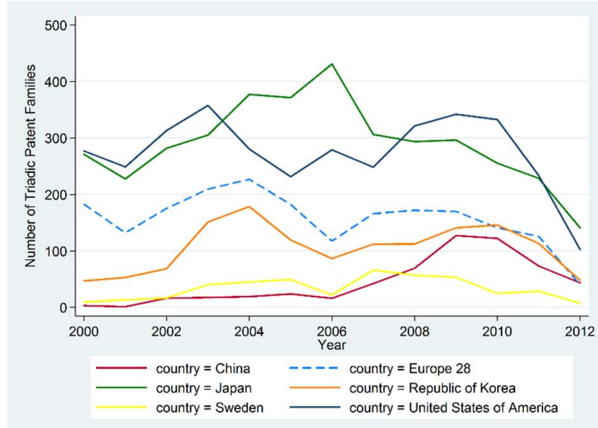
Most of the existing studies about the IoT (Al-Fuqaha et al., 2015; Bandyopadhyay and Sen, 2011; Feki et al., 2013) has put emphasis on the scientific theory and the engineering design, focusing on the technical aspects underlying the IoT. Conversely, the analysis of innovation dynamics in the IoT domain has been so far neglected. To the best of our knowledge, this study represents one of the first attempts to provide a comprehensive picture of the innovation dynamics in the IoT. It provides insights that are potentially useful for managers and policymakers, aimed at understanding how to design innovative activities in this domain. Indeed, despite the fact that the IoT domain

Table 8
Wireless transmissions technologies: PCT applications and triadic patent families by applicant location (2000–2012).

		PCT applications		Specialization			TPF		Specialization
Rank	Country	Tot. share	Col %	Norm. BI	Rank	Country	Tot. share	Col %	Norm. BI
1	Republic of Korea	3644	26.74	0.492	1	Japan	3785	31.86	0.085
2	Japan	3030	22.23	0.354	2	United States of America	3567	30.02	− 0.099
3	United States of America	2775	20.36	− 0.289	3	Republic of Korea	1376	11.58	0.233
4	China	1522	11.17	− 0.015	4	China	575	4.84	0.082
5	Finland	599	4.40	− 0.095	5	Sweden	433	3.65	0.020
6	Sweden	548	4.02	− 0.165	6	Germany	373	3.14	− 0.094
7	Germany	324	2.37	− 0.311	7	France	322	2.71	− 0.224
8	France	297	2.18	− 0.377	8	Netherlands	290	2.44	− 0.080
9	Canada	225	1.65	− 0.147	9	Finland	258	2.17	0.048
10	Netherlands	224	1.64	− 0.086	10	United Kingdom	256	2.15	0.035
11	United Kingdom	105	0.77	− 0.426	11	Canada	198	1.66	− 0.048
12	Italy	53	0.39	− 0.144	12	Taiwan, Province of China	118	0.99	0.171
13	Switzerland	35	0.26	− 0.484	13	Switzerland	42	0.35	− 0.056
14	Australia	31	0.23	− 0.294	14	Israel	39	0.33	− 0.292
15	Singapore	30	0.22	− 0.195	15	Italy	37	0.31	− 0.117
16	Israel	29	0.21	− 0.618	16	Australia	28	0.24	− 0.177
17	Russian Federation	20	0.15	0.138	17	India	27	0.23	− 0.217
18	Spain	20	0.14	− 0.320	18	Denmark	25	0.21	0.070
19	Barbados	19	0.14	0.101	19	Singapore	14	0.12	− 0.282
20	Denmark	14	0.10	− 0.138	20	Barbados	13	0.11	0.022
21	Luxembourg	12	0.08	− 0.246	21	Virgin Islands (British)	11	0.09	0.217
22	Malaysia	11	0.08	− 0.293	22	Mauritius	11	0.09	0.269
23	Brazil	9	0.07	0.134	23	Austria	9	0.08	− 0.274
24	India	8	0.06	− 0.638	24	Ireland	8	0.07	− 0.346
25	Ireland	8	0.06	− 0.693	25	Spain	8	0.06	− 0.526



(a) share of PCT applications



(b) share of Triadic Patent Families

Fig. 6. Evolution of PCT patent applications and triadic patent families from 2000 to 2012 of top 5 countries in wireless transmissions technologies.

Table 9
Main applicants in wireless transmissions technologies in terms of PCT applications and triadic patent families.

PCT rank	Applicant name	PCT applications	Col %	Applicant %	TPF Rank	Applicant name	TPF	Col %	Applicant %
1	LG	1890	17.39	82.71	1	Qualcomm	614	13.08	54.65
2	Samsung	1021	9.39	61.76	2	NTT DoCoMo	493	10.51	67.78
3	Qualcomm	805	7.41	37.29	3	Samsung	413	8.79	50.97
4	Huawei	661	6.08	19.99	4	NEC	356	7.57	55.47
5	NTT DoCoMo	553	5.09	73.12	5	Fujitsu	293	6.25	51.88
6	Telefonaktiebolaget L M Ericsson	501	4.61	17.92	6	LG	254	5.42	72.17
7	ZTE	471	4.33	23.48	7	Koninklijke philips N V	210	4.46	34.90
8	Nokia	393	3.61	15.71	8	Matsushita Electric Industrial	176	3.75	53.17
9	Panasonic	380	3.49	47.63	9	Telefonaktiebolaget L M Ericsson	149	3.17	36.04
10	Sharp	339	3.12	74.16	10	Interdigital	127	2.70	66.29
11	Intel	322	2.96	32.38	11	Lucent	121	2.57	61.41
12	NEC	277	2.55	44.92	12	Nokia	112	2.39	33.77
13	Fujitsu	275	2.53	49.52	13	Panasonic	107	2.27	45.44
14	Matsushita Electric Industrial	252	2.32	49.88	14	Sony	105	2.24	24.26
15	Kyocera and telecommunications research	218	2.01	82.58	15	Sharp	105	2.23	73.01
16	Institute	194	1.79	59.05	16	Huawei	87	1.85	39.49
17	Koninklijke Philips N V	188	1.73	21.27	17	Motorola	84	1.79	55.95
18	Pantech	170	1.56	99.71	18	Alcatel Lucent	81	1.73	26.97
19	Motorola	170	1.56	24.17	19	Toshiba	67	1.42	35.64
20	Interdigital	146	1.34	48.26	20	Alcatel	57	1.20	41.31

is complex to define and to map, our study provides several interesting findings about where the technological knowledge of IoT is located, which organizations have a leading role in developing IoT solutions, what the patterns of international collaboration are, what the differences are among IoT technological subclasses. Lastly, we provide a picture of the most relevant IoT solutions, as represented by TPF (Dernis and Khan, 2004).

More in detail, first we show that Communication control technologies is the field with the most intense patenting activity (32,802 patents), so it reflects where the majority of innovative efforts are directed. For what concerns Network systems technologies and Wireless transmission technologies, both present patenting activity efforts that are almost a half of the previous category, while Data processing technologies is the technology field with the least number of patents. This evidence may reflect the fact that absolute innovative efforts differ between these technological subclasses and/or that the patenting rate is different (e.g. reflecting the relative effectiveness of patents in protecting inventions).

Second, from a geographical perspective, it is interesting to highlight that two former developing countries (China and the Republic of Korea) are among the most patent-intensive and specialized countries in the IoT. Only the USA and Japan do better in terms of patenting activity. However, this scenario captures what happens in terms of PCT applications, but results change when looking at TPF. In fact, while the USA and Japan maintain their leading position, China and the Republic of Korea can only be considered as followers. This may corroborate the inclination of these countries toward a strategy of technological catch-up before undertaking radical innovative activities.

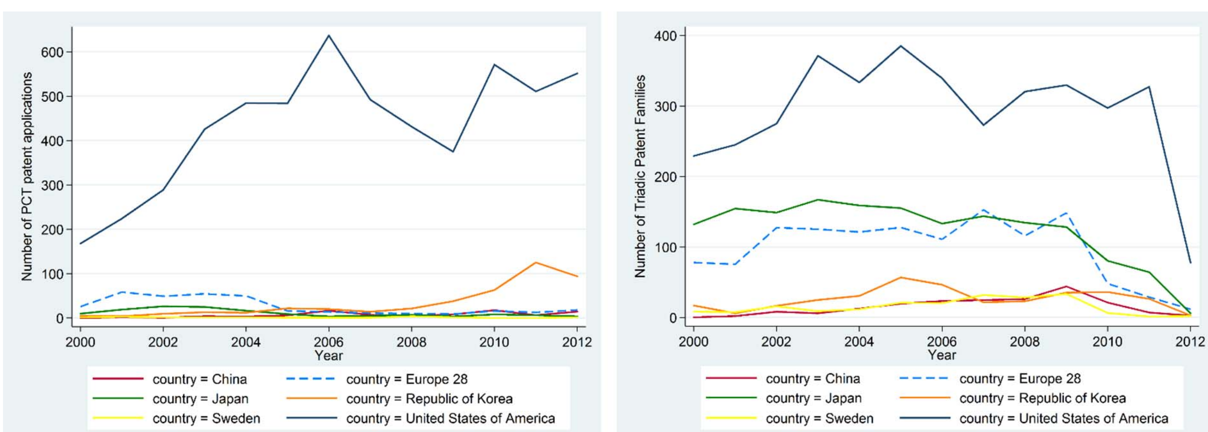
Third, inter-organizational collaborations are not so frequent in the development of IoT technologies, especially collaborations at the international level. This would suggest that the knowledge underlying IoT solutions tends to be geographically bounded and seldom is it shared and exchanged, possibly with negative consequences on the support of standardization and interoperability. Contrary to this evidence, Scuotto et al. (2016) reveal that the effective implementation of IoT networks is endorsed by a worldwide collaborative approach.

Fourth, the majority of the developed IoT technologies are owned by private companies, as we have shown in the analysis of the most innovative applicants. This may point to the central role of profit-oriented organizations as catalysts of innovative efforts in this domain, while public research organizations and universities seem to play a marginal role. Specifically, among those companies, we find major players in mobile telecommunications and ICT (e.g., Microsoft, Hewlett and Packard, and Google).

From a managerial and policy perspective, our suggestions are threefold. First, our study suggests that international agreements should be underpinned in order to support the evolution of IoT technology, hence facilitating innovative efforts aimed at favoring standardization

Table 10
Data processing technologies: PCT applications and triadic patent families by applicant location (2000–2012).

		PCT applications		Specialization			TPF		Specialization
Rank	Country	Tot. share	Col %	Norm. BI	Rank	Country	Tot. share	Col %	Norm. BI
1	United States of America	5643	78.42	0.360	1	United States of America	3803	49.71	0.152
2	Republic of Korea	441	6.13	− 0.195	2	Japan	1607	21.01	− 0.122
3	Israel	164	2.28	0.433	3	Republic of Korea	344	4.50	− 0.231
4	Japan	143	1.99	− 0.684	4	France	283	3.70	− 0.073
5	Finland	128	1.78	− 0.499	5	Germany	241	3.15	− 0.092
6	China	91	1.27	− 0.801	6	Sweden	198	2.59	− 0.149
7	Australia	81	1.12	0.457	7	China	198	2.59	− 0.226
8	Canada	62	0.86	− 0.444	8	Netherlands	178	2.33	− 0.103
9	France	58	0.81	− 0.712	9	Canada	152	1.99	0.042
10	India	49	0.69	0.433	10	United Kingdom	135	1.76	− 0.065
11	Germany	48	0.66	− 0.745	11	Finland	108	1.42	− 0.165
12	Cayman Islands	37	0.51	0.529	12	Israel	60	0.78	0.128
13	United Kingdom	33	0.45	− 0.615	13	Australia	38	0.49	0.183
14	Singapore	29	0.40	0.112	14	India	36	0.47	0.140
15	Netherlands	25	0.35	− 0.700	15	Taiwan, Province of China	26	0.35	− 0.339
16	Sweden	22	0.31	− 0.897	16	Switzerland	24	0.32	− 0.106
17	Russian Federation	20	0.28	0.436	17	Italy	23	0.29	− 0.142
18	Malaysia	16	0.22	0.202	18	Belgium	22	0.29	0.055
19	Switzerland	16	0.22	− 0.542	19	Spain	20	0.26	0.112
20	Virgin Islands (British)	12	0.17	0.424	20	Singapore	19	0.25	0.097
21	Luxembourg	10	0.14	− 0.001	21	Cayman Islands	17	0.22	0.384
22	New Zealand	9	0.13	0.348	22	Ireland	15	0.19	0.131
23	Norway	5	0.07	− 0.376	23	Austria	14	0.19	0.147
24	Ireland	5	0.07	− 0.628	24	Denmark	12	0.15	− 0.083
25	South Africa	5	0.07	− 0.022	25	Norway	11	0.14	0.144



(a) share of PCT applications (b) share of Triadic Patent Families

Fig. 7. Evolution of PCT patent applications and triadic patent families from 2000 to 2012 of top 5 countries in data processing technologies.

and interoperability, while minimizing redundancy and over-diversification. Second, novel policies should stimulate collaborations in the development of IoT solutions especially between companies, which are the main entities responsible for the development of IoT technologies, in addition to being the actual technology owners. Third, since the implementation of a ubiquitous IoT information network is strongly dependent upon country-level policies, the coordination between corporate executives and policymakers is needed so that technical, economic, and political aspects related to the IoT can be better integrated and both business and social needs may be better linked together.

This research has some limitations that should be acknowledged. First, despite patent analysis being widespread and accepted by existing academic and practitioner-oriented literature, it presents some shortcomings (see Section 2.2). Therefore, our analysis may be complemented and replicated using other data sources (e.g., projects databases). Moreover, it would be interesting to conduct interviews with policymakers and experts in the ICT sector in order to better understand the issues raised by our empirical investigation. Furthermore, it may help to identify technologies whose innovative processes are still ongoing and are not yet present in patent data. Second, we mainly focus our attention on technology development. Future studies may shed light on the processes of commercialization and diffusion of IoT technologies, which may help to assess the impact of the IoT solutions on the market. In line with this argument, it may be relevant to study innovative business models used in the IoT (Kim et al., 2007), whether the IoT commercialization requires niche transitions before entering the mainstream market, and what market acceptance issues are at stake. Moreover, the downstream phases of commercialization (e.g., Olivo et al., 2011; Ardito et al., in press) efforts may help in understanding the IoT technology diffusion processes on the market (e.g., using trademarks). Third, an analysis of the existent policies about the IoT

Table 11
Main applicants in data processing technologies in terms of PCT applications and triadic patent families.

PCT Rank	Applicant name	PCT applications	Col %	applicant %	TPF Rank	Applicant name	TPF	Col %	Applicant %
1	Microsoft Licensing LLC	424	18.01	59.47	1	Microsoft	366	20.25	62.85
2	Microsoft	258	10.96	60.78	2	Sony	126	7.00	29.11
3	Hewlett Packard Development LP	246	10.43	47.99	3	International Business Machines	104	5.78	47.47
4	Google	166	7.03	63.60	4	Qualcomm	97	5.39	8.65
5	Nokia	127	5.40	5.08	5	Samsung	93	5.18	11.55
6	Samsung	119	5.06	7.21	6	Koninklijke Philips N V	76	4.24	12.73
7	Intel	117	4.98	11.78	7	Canon	66	3.66	35.42
8	Cisco	100	4.25	14.54	8	Nokia	64	3.52	19.12
9	Motorola	95	4.04	13.55	9	Fujitsu	61	3.38	10.78
10	Intellectual Business Machines	94	3.99	13.48	10	Telefonaktiebolaget L M Ericsson	60	3.31	14.48
11	Yahoo	62	2.65	48.95	11	NEC	56	3.09	8.72
12	Sony	50	2.13	10.78	12	Hitachi	48	2.63	25.40
13	Qualcomm	40	1.71	1.87	13	RCA Thomson Licensing	45	2.48	19.77
14	Citrix Systems	35	1.49	19.37	14	Ricoh	44	2.45	54.23
15	Huawei	35	1.49	1.06	15	NTT DoCoMo	43	2.39	5.92
16	LG	35	1.49	1.53	16	Alcatel Lucent	39	2.16	12.95
17	Thomson Licensing	31	1.33	6.14	17	Matsushita Electric Industrial	35	1.93	10.51
18	AGCO International	31	1.32	24.80	18	Panasonic	34	1.90	14.65
19	Matsushita Electric Industrial	21	0.89	4.16	19	Intel	30	1.66	25.66
20	Motorola Mobility	20	0.85	6.83	20	Hewlett-Packard Development LP	27	1.52	40.03

may help to understand the types of regulation (e.g., technology push vs. demand pull) that might favor IoT development and diffusion. Fourth, it would be useful to map which types of IoT solutions can be applied to the different IoT applications (e.g., business processes and smart cities) (Lee and Lee, 2015; Lu and Cecil, 2016; Scuotto et al., 2016). Furthermore, how these technologies actually interrelate to create a harmonious interaction between the human and the IoT (Guo et al., 2013) and how they can stimulate the creation of a new digital ecosystem (Karakas, 2009) have remained understudied in this research, thus opening the doors for other interesting lines of inquiry. Finally, while an assessment of the actual economic and societal impact of IoT patented inventions is beyond the scope of our study, we believe it deserves further investigation.

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