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NETWORKS OF INTERNATIONAL PATENT CITATIONS: PATTERN OF GROWTH, SELF-ORGANIZATION AND CHANGE*

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SUMÁRIO

ABSTRACT

This paper investigates networks of cross-border patent citations - the patent assignee as a node and an international patent citation as a link. The data (patents and their international citations, selected years between 1991 and 2009) show a network growing over time - more institutions, more links and more countries - and preserving its scale-free properties, a self-organized system with changes in technological specialization. This firm-led network is compared to a network of international colaboration in science - a university-led network. The overlaping of those two international self-organized systems might be a source of an emerging international system of innovation.

Key-words: Patent Citations; International Knowledge flows; Innovation Systems

JEL classification: O32, O34, O39

RESUMO

Este artigo investiga redes de citações internacionais de patentes - o titular da patente como o nó e uma citação internacional da patente como o link. Os dados (patentes e suas citações internacionais, entre 1991 e 2009) mostram uma rede crescendo ao longo do tempo - mais instituições, mais ligações e mais países - e preservando suas propriedades sem-escala, um sistema auto-organizado com mudanças na especialização tecnológica. Essa rede liderada por empresas é comparada a uma rede de colaboração internacional em ciência - uma rede liderada por universidades. A sobreposição desses sistemas internacionais auto-organizados pode ser fonte de um sistema internacional de inovação em formação.

Palavras-chave: Citações de Patentes; Fluxos internacionais de conhecimento; Sistemas de Inovação

Classificação JEL: O32, O34, O39

INTRODUCTION

Patent citations (Jaffe et al, 2002) and their networks (Breschi et al, 2004; Erdi, 2016; Valverde, 2014; Érdi et al, 2013) have been discussed in the literature. Focusing in international or cross-border patent citations (Jaffe et al, 1999), the contribution of this paper is the investigation of networks of those international patent citations. The investigation of networks of cross-border patent citation unveils international knowledge flows, an important phenomenon for discussions related to a transition "from national to international innovation systems" (Soete et al, 2010, p. 1176).

Networks of patent citations have been investigated in the literature - examples of this literature are Érdi et al (2013, p. 227) and Strandburg et al (2009, p. 1660). Those investigations defined the components of their network clearly: for example, Erdi et al (2013, p. 227) defined that in their study, "...the patent citation network is comprised of patents (nodes) and the citations between them (links)".

In a dialogue with this literature, our paper defines differents links and nodes, therefore a different network. The focus on international networks defines the unit of analysis of this paper: a cross-border patent citation - a proxy for an international knowledge flow. The identification and measurement of those cross-border patent citations might contribute to a further understanding of international flows that tension and connect national systems of innovation.

This unit of analysis leads to a first difference in our network: its *link* is a cross-border or international patent citation. A second difference is related to our definition of *node*: the *node* of our network is an institution (patent assignee), that could be a firm, a research institution, a government agency or even individual inventors.[1]

The investigation of this specific network formed by the combination of our link (international patent citation) and our node (the institution that owns the patent, the patent assignee) is the contribution of this paper.

The investigation of the nature and dynamics of this network is the objective of this paper. Basic questions on this investigation are: Does the number of links and nodes grow over time? Does this network spread globally? Is this network a random network? Is it static or has it dynamic properties? If dynamic, how does it evolve over time?

Table 1 shows its growth: between 1991 and 2009 the total of patents, of patents with citations and the total of patents with international citations grew. The number of cited countries also grows, a hint of the growing internationalization - or global reach - of this network. Using Patstat, a database was prepared with USPTO patents for selected years between 1991 and 2009, totalling 1,022,490 patents, 786,780 patents with international citations and 4,064,995 cross-border citations, according to Table 1.

[1] In a previous work (Britto et al, 2019a) we studied one institution (IBM) and its patent citation network.

TABLE 1
Basic statistics: patents, citations, countries cited and links
(1991 – 2009)

Year	Patents	Citing Patents	Inter. Cititing Patents	Cited Countries	Citations
1991	104,981	101,486	70,390	96	210,271
1994	115,183	111,172	80,886	104	276,052
1997	133,066	127,472	93,801	114	364,997
2000	157,545	154,104	137,102	123	597,435
2003	169,875	166,545	139,286	143	757,992
2006	174,495	171,431	132,683	146	862,952
2009	167,345	165,769	132,632	151	995,296

Source: PATSTAT, authors' elaboration

There are other evidences of the internationalization of patent citations in Table 1. In 1991, 67.1% of the patents cited a patent from abroad, in 2009 this percentage grew to 79.3%. In 2009 the total of patents with international flows was greater than the total of patents in 1994 and almost the same as in 1997. The international reach of this network is also shown in Table 1: in 1991 there were 91 cited countries and in 2009 there were 151 countries.

Those evidences of growth in the network of international patent citations put forward questions on the nature of its growth and other dynamic properties.

International patent citations as a channel of international flow is very difused, but there are other channels through patents. Ribeiro et al (2016) present other different internationalization measures using patents. Four of them (flow assignee-author, flow GUO-assignee, flow co-author, and flow co-assignee) have been used in the literature (see Guellec et al, 2004 and Laurens et al, 2015). Ribeiro et al (2014) investigated another measure: patent citation of foreign ISI-indexed papers.[2]

International patent citations constitute a broader source of international flows than the other five, but they might combine and overlap in the internationalization of knowledge flows. Since those international flows through patent citations are so generalized, they might form a network connecting different firms and other institutions that patent. The size of this network of international citations totals 4,064,995 links.

This investigation is organized in five sections. The first section reviews the literature on patent citations and their networks, to locate those networks within a broader process of emergence of rudiments of an international system of innovation. The second section presents our database, and how it may be used to investigate the specific nature of this network, with institutions as nodes and international patent citations as links. The third section deals with the

[2] For a comparison with the other four internationalization indicators used in the literature, statistics for 2010 prepared by Ribeiro et al (2016), investigating triadic patents, shows the percentages of each international flow vis-à-vis the total of patents. The percentages are as follows: 1) international flow Assignee in one country, Inventor in another country: 11%; 2) international flow GUO (the owner of the group) in one country, the Assignee in another: 4%; 3) international co-authorship (inventors in different countries): 7%; 4) Assignees in different countries: 1%. The fifth international flow was investigated in Ribeiro et al (2014): for USPTO patents in 2009, 5.9% cited foreign ISI-indexed papers.

basic structure of this network, evaluating how those links are distributed by countries and investigating the nodes of this network - what are the relevant institutions, how they are linked through patent citations. The fourth section investigates the properties of this network, specially its stability, its growth and whether it is a self-organized system. The fifth section compares the network of international patent citations with the networks organized around scientific production and asks how far those networks might have gone in the transition between national and international systems of innovation.

I. LITERATURE REVIEW: PATENT CITATIONS AND NETWORKS OF INTERNATIONAL KNOWLEDGE FLOWS

Since the seminal analysis from Arrow (1962) on the contradictory role of patents as source of information and as a monopoly, stocks of patents organized by patent offices (see www.uspto.gov, as an example) may be investigated as rich source of technological information. Results of patent searches provide free access to this stock of knowledge codified in patent documents.

However, Arrow (1974) also puts forward a very specific cost to use this knowledge: previous investments in knowledge and infrastructure would be necessary to access and understand those stocks of technological information available. This insight is related to a rich literature on absorptive capabilities necessary to use this knowledge (Cohen and Levinthal, 1989, 1990).

Patent citations are a proxy of how the available stock of knowledge may be used as source for new patents (Jaffe and Trajtenberg, 2002).[3] Patent citations, therefore, contributes to understanding two sets of agents: first, those who generate and "own" knowledge - patent owners (or patent assignees of cited patents) - and, second, those who can learn and use information of that accumulated stock of knowledge to further technological innovation - institutions that use that knowledge and leave tracks of this use in citing patents, the patent assignee of the citing patent. The investigation on patent citations may uncover those two sides of R&D (Cohen and Levinthal, 1989), as firms may invest in R&D to generate new knowledge (that may lead to a patent) and also invest in R&D to learn - to understand information accumulated in the stock of patents (that may lead to learning that will create a new patent, now with a citation to previous patents). Those firms that create technology can learn, and firms that learn from other firms can create new technology. The database on patents and patents citations may uncover who does what in those knowledge flows.

Jaffe and Trajtenberg (1999) also pioneered the use of patent citations to understand international flows.[4] Hu and Jaffe (2003) investigated how kwowledge diffused from US and

[3] For a broad review of the literature on knowledge flows through patent citations, see Britto et al (2019a, sub-section 2.3).

[4] For a broad review of the literature on *international* knowledge flows through *cross-border* patent citations, see Britto et al (2019b, section 1).

Japan to Korea and Taiwan during their catch up processes. This literature provides the foundation for our basic unit of analysis - cross-border patent citation as a proxy for an international knowledge flow.

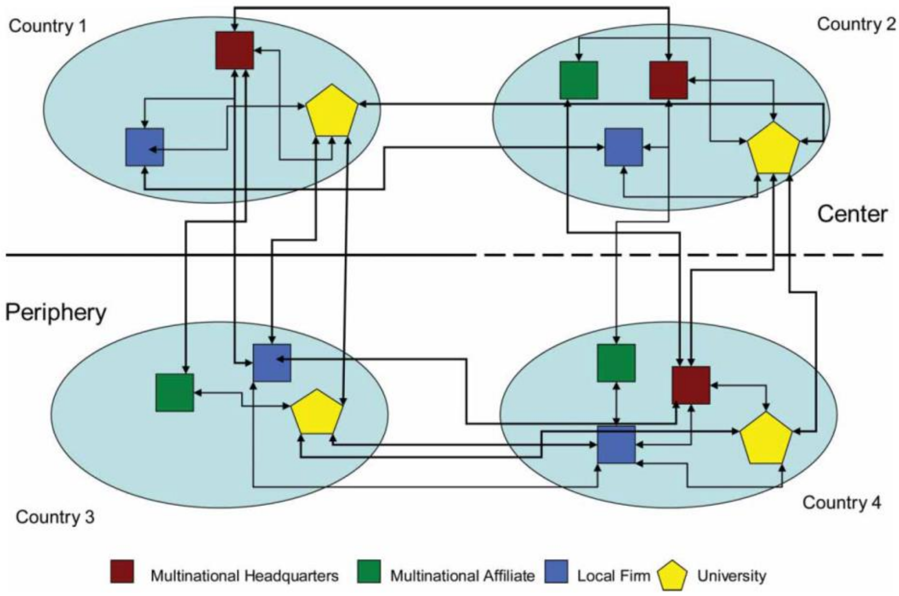
Patent citations form networks. Those networks of patent citation have been investigated by a rich literature (Érdi et al, 2013; Érdi, 2016; Valverde, 2014; Valverde et al, 2007). Those investigations evaluate properties of those networks, uncovering their growth (Valverde, 2014, Figure 2), their fequency distribution over time (Strandburg, 2009, p. 1669), their stratification (Strandburg, 2009, p. 1670), the powe-law property of those distributions (Valverde, 2014, p. 3), characteristics of specific networks for different products (Valverde, 2014) and use of those networks to predict emerging technologies in specific patent classes (Érdi et al (2013).

International knowledge flows have been investigated, but for flows related to scientific papers (Wagner et al, 2005; Wagner et al, 2015). The properties of those networks were investigated by those pioneering studies, that found power-law properties and self-organization. Ribeiro et al (2018) integrate this literature, discussing the dynamic growth of networks of scientific international colaboration.

Investigations of properties of networks, especially non-random networks and their self-organization properties were inaugurated by Barabási and Albert (1999), and those tools were used by Wagner et al (2005) and Valverde (2014) to investigate networks of colaboration in scientific papers and patent citations. This literature provides the basis for our investigation on networks of international patent citations.

Those networks of international patent citations might be part of a broader framework of international knowledge flows. Figure 1 summarizes those flows, graphically illustrating case studies described in the literature (see Britto et al, 2013) - each flow drawn in Figure 1 is supported by a specific study. There are flows within transnational corporations (both tacit and codified knowledge), there are flows connecting different universities, there are flows between firms and universities and flows between different firms - patent citations are one of the sources of those flows.

FIGURE 1
Multinationals, their R&D activities and the scientific institutions as connectors between different national systems of innovation - a tentative framework



Source: Britto et al (2013, p. 80)

This tentative theoretical framework (Britto et al, 2013) informs an important choice for our analysis of the network of international patent citations: institutions (that could be firms or universities, inter allia) as patent assignees. The network that this paper investigates is built upon decisions and actions taken by those key agents, and they shape the formation and evolution of those networks.

At this stage, those international flows are growing in importance (see Ribeiro et al, 2014, 2018; Britto et al, 2019a, 2019b) and they connect different national innovation systems, putting forward new issues, oppening new opportunities and new challenges. Between the challenges facing those more internationally connected national systems of innovation (Silva, 2014), there is a growing tension between the forces of internationalization and national frontiers of each innovation system. An investigation of networks of international patent citations might help to understand this source of connection and tension among national systems of innovation (Soete, 2010, p. 1176).

II. DATA AND METHODOLOGY

The Patstat database was used as source to provide data needed to build the network as described in Introduction. That database is organized by the European Patent Office (EPO) and covers almost 70 million patents from more than 100 patent offices around the world and some of those patents are as early as the nineteenth century.

For this research we used only data extracted from the USPTO, for two main reasons. First, by choosing one specific patent office we would be analysing patents granted through the same evaluation and burocratic processes - a sorce of homogeneity. Second, choosing the US patent office we are using a patent officie that sometimes is a proxy for a global patent office, given the size of the US market and the propensity that this induces in institutions (firms, universities, individuals) to patent there.

The data processing by Patstat provides a broad temporal coverage that is important for this work, as the patents cited are also in this database - a patent granted in 2009 may cite patents from any time before 2009. The data collection for our investigation is limited to the first level of citation - we did investigate only citations in the patents granted in each selected year (2009, 2006, 2003, 2000, 1997, 1994 and 1991), and at this stage we did not proceed investiganting citations in the cited patent. However, patents cited in one year may cite patents from several different years. This is one reason why in Table 1, patents from 2009 cited patents from 151 different countries, although in 2009 there were patents granted for only 101 countries).

For the formation of the network to be analysed in this paper, the node, as already stressed in the Introduction, is the patent assignee (the first patent assignee). The patent assignee as a node allows an analysis of this network investigating the owner of the monopoly rights, the institution that may extract economic rents or other competitive advantages from this ownership. This option incurs in problems related to the location of the invention - normally the address of the first inventor -, but since our focus is a knowledge flow, this difference between the assignee country and the inventor country is a source of one specific international flow (see Introduction), that will not be analysed here.

This focus in patent assignees put forward an important research question about the nature of that assignee, about what institution is it: a firm, a university, a government agency?

Once our processing of the database generated a set of patents per year, the second step is to identify if that patent cites patents from assignees from other countries (first patent assignee of the cited patent). If yes, those patents are filed, and each citation leads to the link of our investigation - an international patent citation. The link, therefore, connects two patents, with two different patent assignees, two different countries - a pair of patent assignees. Those links shape the network that will be investigated, using the tools created by Barabási and Albert (1999).

The data collected in each patent includes the sectoral classification of the patent (for the citing and cited patents), according to the USPTO classification. This sectoral classification is an input for the preparation of our matrices of international technological. Those matrices, processing the original USPTO classes through an algorithm suggested by the Observatoire des

Sciences et des Techniques (OST, 2006), that aggregates those classes into 30 different technological subdomains (see Appendix Table A1 for this list).[5] Those matrices of international technological flows show how the network that we investigate changes over time its technological specialization.

III. A NETWORK OF FIRMS, INSTITUTIONS AND COUNTRIES CONNECTED BY PATENT CITATIONS

This section describes the basic statistics of the network of patent citations. First, it describes its nodes - patent assignees - and the links (international patent citations) that each of them have. Second, those data are rearranged to see how countries aggregate those links.

III.1. Firms and Institutions as Nodes

In 2009 there were 148,051 different patent assignees - different institutions. The distribution of links (international patent citations) accross those nodes is very concentrated: the first 500 nodes have 451,234 links - almost the same total as the remaining 147,551 nodes.

[5] Ribeiro et al (2010) present a matrix for interaction between science and technology, a starting point for the preparation of Figure 2. Britto et al (2019b) show matrices of international patent citations, with the same methodology used in this paper, but prepared from a different database (USPTO, not Patstat).

TABLE 2

Leading nodes (hubs): citing patent assignee name, citations, patents and institutions cited, countries from which they absorb knowledge

(2009)

	Assignee Name	Citations	Patents	Institutions	Countries
1	International Business Machines Corporation	16,560	8,763	2,100	47
2	Hitachi, Ltd.	16,195	10,370	3,191	46
3	Kabushiki Kaisha Toshiba	15,637	9,262	2,658	44
4	Fujitsu Limited	13,179	9,072	2,505	41
5	Samsung Electronics Co., Ltd.	12,420	8,583	2,248	42
6	Sony Corporation	11,728	7,022	2,198	45
7	Matsushita Electric Industrial Co., Ltd.	11,659	7,598	2,479	45
8	Canon Kabushiki Kaisha	11,194	6,398	2,019	39
9	NEC Corporation	10,916	7,692	2,192	46
10	Mitsubishi Denki Kabushiki Kaisha	8,190	5,740	1,927	38
11	Intel Corporation	6,335	3,984	1,123	39
12	Siemens Aktiengesellschaft	6,276	4,857	1,976	40
13	General Electric Company	6,047	2,851	1,248	40
14	Motorola, Inc.	5,692	3,953	1,196	40
15	Nortel Networks Limited	5,458	3,727	1,048	29
16	Micron Technology, Inc.	5,355	2,599	692	30
17	Texas Instruments Incorporated	4,897	3,350	975	40
18	Eastman Kodak Company	4,848	2,599	777	37
19	Sharp Kabushiki Kaisha	4,826	3,536	1,202	34
20	Koninklijke Philips Electronics N.V.	4,687	3,684	1,341	33
21	Microsoft Corporation	4,486	2,478	725	41
22	Xerox Corporation	4,344	2,549	647	38
23	Nokia Corporation	4,324	3,130	987	31
24	Seiko Epson Corporation	3,927	2,836	991	33
25	Hewlett-Packard Company	3,577	2,397	737	35
26	Robert Bosch GmbH	3,546	2,367	1,111	32
27	Hewlett-Packard Development Company, L.P.	3,237	2,383	703	33
28	Lucent Technologies Inc.	3,096	2,360	790	36
29	Telefonaktiebolaget LM Ericsson (publ)	3,020	2,335	758	26
30	Infineon Technologies AG	2,947	2,303	736	30

Source: PATSTAT, authors' elaboration

Table 2, data for 2009, shows the 30 leading nodes of this network, according to the total of links (cross-border patent citations) that each node has. Table 2 shows only one type of institution - firms. Given the role of transnational corporations in those flows, according to the framework presented in Figure 1, this ranking is not surprising. Those firms are the leading absorbers of technology through information disclosed in patents.

IBM leads this ranking, with 16,560 cross-border patent citations, to patents from 2,100 different institutions from 47 different countries.[6] Over time this ranking changes: in 1991 IBM was in the third position, behind Hitachi and Siemens. In 1991 cross-border patent citations

[6] Unfortunately, there are remaining different identifications for IBM (IBM Corporation and IBM Corp.), besides typos and other minor mistakes. This means that IBM would have more citations than those shown in Table 2 - the total would be 17,941 citations. Since it was not feasible to correct all database, and those mistakes would be distributed among all institutions, we decided to use those data mentioning its problems. There would be no change in the ranking. and the hierarchical nature of this network would be more unequal than shown in section IV. Other differences derive from decisions of the firms - IBM seems to put all patents under the ownership of IBM in the US, while Novartis distributes its ownership through its different divisions and subsidiaries.

connected IBM with 477 institutions from 22 different countries. In a previous paper, Britto et al (2019a) describe changes in IBM patent citations, both quantitatively and qualitatively, showing how this transnational corporation increased the number of citations and moved to new technological sectors.[7]

The first university in the ranking presented in Table 2 is the University of California - 62nd position,[8] with 1,198 citations from 34 countries. MIT follows in the 73rd position, University of Princeton in the 216th position and Stanford University is in the 226th position.

The first government agency in Table 2 ranking is the "United States of America as represented by the Secretary of the Navy", in the 91st position, with 888 international citations, from 37 different countries.

Individual inventors (identified by no assignee name, or by an assignee name equal to the inventor name) are present around the 502th position, with 20 citations.

Table 3 presents another point of observation of this network, focusing in the pairs of institutions that each link connects - it presents a ranking of the leading pairs, showing the two institutions connected by cross-border patent citations. Table 3 also presents only firms as nodes connected in those 20 leading pairs. As an evidence that the two sides of R&D (Cohen and Levinthal, 1989) are deeply correlated, four firms are in Table 3 both as citing and cited assignee.

The links described in Table 3 suggest that there is also a huge concentration in the distribution of those links. For instance, IBM (as a citing institution) in three links presented in Table 3 concentrates 14.5% of all its links with connections with only three firms.

[7] For a comparison with other networks of international knowledge flows, IBM is at 1,230th position in 2015 in the ranking of institutions with international co-autorships (Ribeiro et al, 2018). The first firm in that ranking is Novartis, which is in the 545th position (with more than 5,000 connections) - Novartis is in the 175th position in the ranking presented in Table 2.

[8] University of California would be the first research institution in the ranking of institutions with international co-autorships (Ribeiro et al, 2018), if we put together all campi, as is the case with its patents. In the WebOfScience, scientific papers have addresses of the specific campus of the University of California, spread through its nine campi - UC Berkeley is the 56th with 32,536 international co-authorships, UC Irvine in the 125th position with 24,554 international co-authorships. If we add the co-authorships of all campi, University of California total would be 176,699 international co-authorships (almost three times the total of Oxford University, the first institution in that rankinng). Oxford University leads the ranking of international co-authorships and it has only two links in our database (a quick search at the USPTO database shows only 2 patents granted in the years of our database). Cambrige University, second at the ranking of international co-authorships has only 17 links in our database (patent assignee: Cambridge University Technical Services Ltd). MIT is 25th in international co-autorships.

TABLE 3

Leading links (international patent citations) and its pairs: patent assignee of the citing and cited patent, citations and patents

	Citing Assignee Name	Cntry	Cited Assignee Name	Cntry	Citations	Patents
1	Kabushiki Kaisha Toshiba	JP	SanDisk Corporation	US	1,216	162
2	Micron Technology, Inc.	US	Macronix International Co., Ltd.	TW	1,053	55
3	Hitachi, Ltd.	JP	International Business Machines Corporation	US	1,039	691
4	Matsushita Electric Industrial Co., Ltd.	JP	LG Electronics Inc.	KR	1,028	256
5	Sony Corporation	JP	Microsoft Corporation	US	990	407
6	Sony Corporation	JP	LG Electronics Inc.	KR	925	205
7	Kabushiki Kaisha Toshiba	JP	Samsung Electronics Co., Ltd.	KR	917	561
8	International Business Machines Corporation	US	Samsung Electronics Co., Ltd.	KR	878	545
9	International Business Machines Corporation	US	SAP AG	DE	874	210
10	Kabushiki Kaisha Toshiba	JP	Micron Technology, Inc.	US	833	368
11	International Business Machines Corporation	US	Hitachi, Ltd.	JP	810	284
12	Samsung Electronics Co., Ltd.	JP	Micron Technology, Inc.	US	770	363
13	General Electric Company	US	Sabic Innovative Plastics IP B.V.	NL	729	48
14	Fujitsu Limited	JP	International Business Machines Corporation	US	719	572
15	Matsushita Electric Industrial Co., Ltd.	JP	Samsung Electronics Co., Ltd.	KR	659	395
16	International Business Machines Corporation	US	Hitachi Global Storage Technologies Netherlands B.\	NL	645	223
17	Micron Technology, Inc.	US	Samsung Electronics Co., Ltd.	KR	634	342
18	Canon Kabushiki Kaisha	JP	Silverbrook Research Pty Ltd	AU	632	257
19	Xerox Corporation	US	Silverbrook Research Pty Ltd	AU	618	281
20	Kabushiki Kaisha Toshiba	JP	International Business Machines Corporation	US	617	481

Source: PATSTAT, authors' elaboration

Table 4, a ranking of the 21 leading cited patent assignees also display only firms in those positions. Those firms are the leading diffusers of technology through information disclosed in their patents.

Among those 21 firms, 10 are also in leading positions as citing patent assignees - a hint on the two faces of R&D: firms that use other firms' stock of knowledge also provide knwoledge to other firms. This phenomenon might be also another evidence on Rosenberg suggestion that firms would invest their money in basic R&D as an entry ticket to flows of knowledge (Rosenberg, 1990).

TABLE 4
Leading nodes (hubs): cited patent assignee name, citations, patents and institutions citing, countries to which they diffuse knowledge
(2009)

	Assignee Name	Citations	Patents	Institutions	Countries
1	Samsung Electronics Co., Ltd.	23,572	3,053	5,357	42
2	International Business Machines Corporation	13,162	3,622	2,931	56
3	LG Electronics Inc.	12,259	916	2,616	43
4	Microsoft Corporation	12,088	2,158	2,175	55
5	Micron Technology, Inc.	10,690	901	1,450	38
6	Sony Corporation	9,177	1,383	3,833	43
7	Silverbrook Research Pty Ltd	8,089	464	1,318	26
8	Canon Kabushiki Kaisha	7,558	1,624	2,864	40
9	Panasonic Corporation	7,333	1,474	3,267	40
10	Fujitsu Limited	6,887	1,104	2,677	35
11	Kabushiki Kaisha Toshiba	6,776	1,351	2,605	32
12	Nokia Corporation	6,741	634	2,545	40
13	Hitachi, Ltd.	6,722	891	2,434	35
14	Intel Corporation	5,438	1,190	1,439	37
15	Hewlett-Packard Development Company, L.P.	5,314	1,025	1,756	44
16	Seiko Epson Corporation	5,199	1,018	1,971	35
17	SAP AG	5,059	308	1,481	24
18	Infineon Technologies AG	5,057	577	1,802	32
19	Siemens Aktiengesellschaft	4,903	667	2,492	36
20	Semiconductor Energy Laboratory Co., Ltd.	4,807	497	1,213	24
21	Cisco Technology, Inc.	4,690	753	863	31

Source: PATSTAT, authors' elaboration

III.2. AGGREGATING BY COUNTRIES

Table 5 organizes the data by countries, aggregating the total of cross-border patent citations according to the location of the patent assignee. Developed countries' national systems of innovation lead the ranking – US, Japan, Germany and Canada are the four countries that more intensively access the international stock of knowledge available through patents. Those systems of innovation lead the absorption of technology generated in other countries.

Table 5 shows how recently successful catch up countries (South Korea and Taiwan) ranks well in this regard – 6th and 8th positions, and how China is improving her position (in 2009 in the 20th, an improvement compared to the 35th position in 1991).

In the ranking shown in Table 5, the first country at the periphery – besides China - is at the 29th position: South Africa. Russia (37th), Argentina (38th), Brazil (39th) and Mexico (40th) follow.

TABLE 5
Leading countries according to aggregated patent citations: total citations and patents (2009)

	Country of Citing Inventor	Citations	Patents
1	US	382,265	62,822
2	JP	254,040	66,705
3	DE	71,047	34,511
4	CA	41,240	23,900
5	GB	32,632	19,966
6	KR	31,629	18,755
7	FR	30,889	19,124
8	TW	30,240	16,116
9	SE	17,532	11,318
10	NL	15,360	10,458
11	CH	14,062	9,267
12	IL	11,331	7,809
13	FI	11,248	7,190
14	IT	9,735	7,009
15	AU	7,000	4,960
16	DK	3,585	2,394
17	BE	3,462	2,681
18	SG	3,386	2,889
19	AT	2,343	1,804
20	CN	1,867	1,565
21	HK	1,755	1,411
22	NO	1,718	1,382
23	IE	1,604	1,285
24	ES	1,095	937
25	BM	1,091	862
26	LI	949	679
27	NZ	945	761
28	KY	944	655
29	ZA	939	696
30	VG	859	726

Source: PATSTAT, authors' elaboration

Table 6 shows the pairs of countries, highlighting how those flows are concentrated among developed countries – there are no countries at the periphery in the 30 leading pairs. Recently successful catch up countries (South Korea and Taiwan) are in this list, both citing US patents (respectively pairs number 12 and 13). However, both ranks better as source of knowledge (countries of cited patents, South Korea in positions 6 and 7, Taiwan in position 10).

Table 6 also show again how the two sides of R&D are present, as countries in the ranking are listed as citing patents and as with patents cited. The US, for example, are 12 times in pairs as a country of a citing assignee (absorbing technology) and 13 times as a country of a cited assignee (diffusing technology).

TABLE 6

Leading inter-country links (international patent citations) and its pairs: country of the citing and cited patent, citations and patents

(2009)

	Country of Citing Inventor	Country of Cited Inventor	Citations	Patents
1	JP	US	170,239	41,878
2	US	JP	117,356	25,615
3	DE	US	47,065	21,271
4	US	DE	43,357	7,065
5	CA	US	31,541	17,096
6	US	KR	29,977	6,607
7	JP	KR	26,041	6,189
8	US	CA	25,516	2,274
9	GB	US	23,943	13,935
10	US	TW	22,435	4,686
11	FR	US	20,970	12,210
12	TW	US	17,779	8,867
13	KR	US	16,659	9,447
14	US	NL	15,427	1,929
15	US	CH	15,001	1,346
16	US	FR	14,826	2,563
17	US	GB	14,644	1,611
18	JP	DE	12,382	4,368
19	US	IL	11,670	842
20	SE	US	11,635	7,269
21	JP	TW	9,955	3,580
22	US	AU	9,868	897
23	DE	JP	9,642	5,610
24	CH	US	9,628	6,142
25	NL	US	9,161	6,383
26	IL	US	8,440	5,601
27	KR	JP	7,707	4,981
28	US	SE	7,549	1,057
29	FI	US	6,953	4,399
30	IT	US	6,397	4,419

Source: PATSTAT, authors' elaboration

IV. THE NETWORK: ITS GROWTH, LONG TERM DYNAMICS AND PROPERTIES

Those data on nodes (institutions) and links (cross-border patent citations) organize an analysis of the network of international patent citations. Barabási and Albert (1999) introduce tools for analysis of non-random networks and their specific properties. Valverde (2014) and Érdi (2016) present analysis of networks of patent citations.

IV.1. Nodes and Links - Size and Growth of the Network

Table 7 summarizes data regarding size, growth and basic features of this network. Between 1991 and 2009, the total of nodes grew 2.58 times and the total of links grew 4.73 times. The growth of those two components of this network is higher than the growth shown in Table 1 for patents and patents with international citations, respectively 1.58 and 1.88 times. Table 1 also shows that the spread of this network through different countries increased 1.57 times. Those comparisons show that the network has a pattern of growth more intense than its basic components – patents and countries involved.

TABLE 7
Basic network statistics:
nodes, links, average links per node and exponents of the power-law distribution
(1991 – 2009)

Year	Nodes	Links	Average Links per Node	Exponent
1991	57,279	210,271	3.67	
1994	70,573	276,052	3.91	2.06
1997	84,982	364,997	4.29	2.09
2000	121,884	597,435	4.90	2.09
2003	145,475	757,992	5.21	2.06
2006	138,965	862,952	6.21	2.06
2009	148,051	995,296	6.72	2.03

Source: PATSTAT, authors' elaboration

As the growth of links (international patent citations) is greater than the growth of nodes (institutions, patent assignees), the level of connectiveness of each node also increases, as shown in Table 7: in 1991 there are 3.67 links per node, and in 2009 in reaches 6.72 links per node.

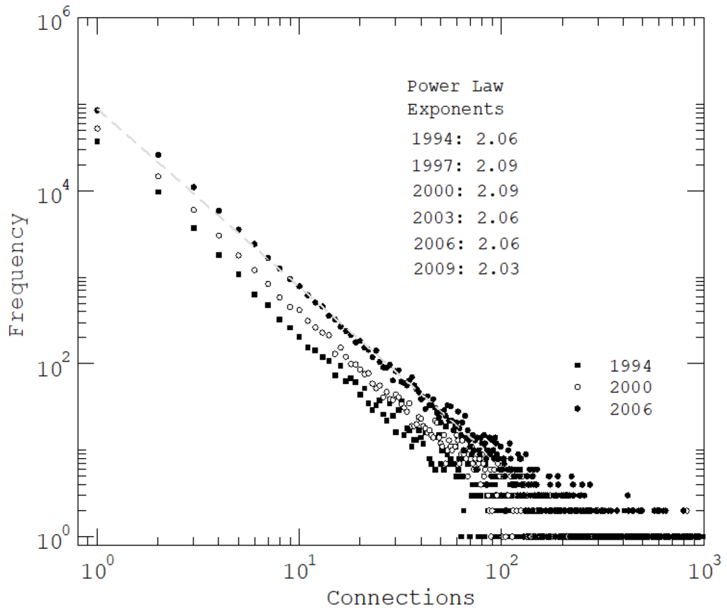
The nature of the distribution of those links per node is initially evaluated in the previous section, that highlighted how the leading institutions (mainly firms) concentrated a huge number of links. Those links also are very strong between leading pairs (connections between two nodes of the network), also indicating an uneven distribution of those connections – hints of a hierarchical organization of this network. The exponents shown in Table 7 further suggest a hierarchical organization of this network.

IV.2. Properties of the Network: Scale-Free and Self-Organization

The pattern of long-term growth of this network is presented in Graph 1, that investigates that nature of this frequency distribution of links per node, from 1991 to 2009.

Graph 1 shows that the network grows preserving its basic structure. The network displays a power law distribution of connections, in all those years – few nodes (hubs) have many links, many nodes have few links. The identification of this power law distribution highlights the scale-free nature of this network, an indication of the self-organization of this network.[9]

GRAPH 1
HISTOGRAM: distribution of patent assignees (nodes) with patent citations according to the number of international patent citations (links)
(1991, 2000, 2009)



Source: PATSTAT, authors' elaboration

The exponents of those power law distributions are shown in Table 7 – relatively constant over time, around 2.05. This stability suggests the preservation of the hierarchical distribution over time, a feature of this self-organized system that expands – as shown in Tables 1 and 7 –, with more patents, more patents with international citations, more countries cited in patents, more nodes and more links, while preserving its basic structure.[10]

The structure of this network of international patent citations is slightly different from the structure described by Valverde (2007, p. 3; 2014, p. 3): his network is "neither exponential nor a simple power law" (2007, p. 3). Probably this difference lies in our definition of node – the

[9] To a cleaner expression of those data, the exponents were calculated for all years presented in Table 7, but the Graph shows the curves only for three selected years – 1991, 2000 and 2009.

[10] Those exponents can be compared to the network of scientific co-authorships, whose exponents are around 1.75 (Ribeiro et al, 2018, Table 5). For the sub-network that involved only firms as first author and their scientific co-authorships (Ribeiro et al, 2018, Table 7), the exponents are closer to those of the network of international patent citations. Those comparisons indicate that the network of international patent citations is more hierarchical than the network (and sub-network) of international scientific collaboration.

patent assignee, an institution, predominantly a firm, as shown in section II. Valverde's node is a patent – patent may have many or few citations, but an institution may accumulate much more patents and their citations, reaching larger order of magnitude.

The network of international patent citations organized by institutions (mainly firms, with an important role for transnational corporations) has properties of scale-free networks, following a simple power law distribution – without deviations -, a characterization that is enough to highlight its self-organization – an important finding to open further research on the meaning of this international network.

Self-organization stresses the stability of this network, its resilience, therefore, its role as a structural feature of contemporary economy.

IV.3. Dynamics of the Network: Matrices of Patent Citations and their Long-Term Changes

This network grows, self-organizes and reproduces its basic and hierarchical structure. Furthermore, it is necessary to investigate its long-term evolution and possible changes in its technological specialization.

To investigate this long-term evolution, Figure 2 shows, for selected years, global matrices of technological interaction between cross-border flows among citing and cited patents. Those matrices are organized through the 30 different technological subdomains (see Appendix Table A1 for this list) suggested by OST (2006).

An intertemporal comparison between those matrices might show how this self-organized system moves over time. Those matrices evaluate our links – cross-border patent citation – through the investigation of each matrix cell, that contains the technological class of the citing patent (x-axis) and the technological class of the cited patent (y-axis). In other words, how the new knowledge (citing patent) is using the stock of knowledge (cited patents). The intensity of this use might be measure by third axis (z-axis), that shows the number of citations (cross-border patent citations) for that cell – the height of the cell is shown in each matrix.

Over time, the number of cells with international citations has grown – the matrix fulfillment grows -, the height of cells grows (see the order of magnitude in the z-axis growing between 1991 and 2009), and the position of the peaks change. Comparing the three matrices in Figure 2, there are movements that differentiate those three snapshots of the network of international patent citations through the lens of technological classes.

There are four main changes in this network over time.[11]

First, the growth in the network and in the number of links is reflected in Figure 2 through the height of z-axis: the leading peak (cell with more citations) was around 0.2 million citations in 1991, 0.6 million citations in 2000 and 1.3 million in 2009.

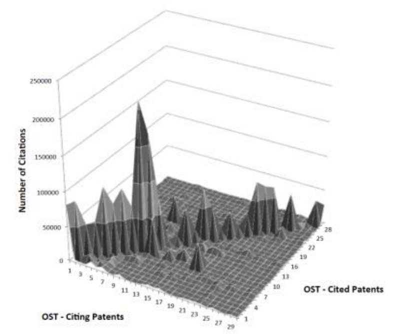
Second, over time peaks outside the diagonal become more relevant, as the first non-diagonal peak in 2009 is the 7th position (OST 11 x OST 9), while in 1991 the first non-diagonal peak is in the 21st position (OST 19 x OST 9). This means a process that suggests that at least for

[11] For a broader list of different indicators such as fulfilment indexes, diagonalization indexes, concentration of leading cells, etc, that can be used in the analyses of those matrices, see Britto et al (2019b).

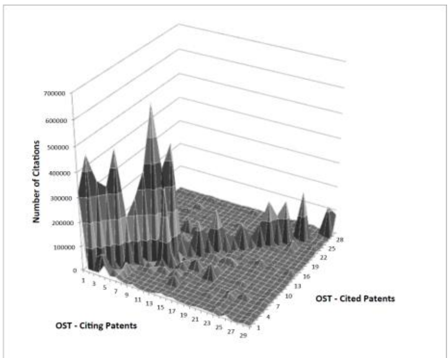
some OST subdomains there is a need to absorb more knowledge from other OST subdomains for their development - a movement towards greater inter-sectoral absorption and diffusion.

Third, there are movements in the ranking of peaks, the leading peaks always being with the same OST subdomain as in the citing and in the cited patent. In 1991 the first five peaks are organic fine chemicals (OST 9), macromolecular chemistry (OST 10), semiconductors (OST 5), analysis, measurement and control (OST 7) and audiovisual (OST 2). In 2009 they are organic fine chemicals (OST 9), telecommunications (OST 3), semiconductors (OST 5), audiovisual (OST 2) and information technology (OST 4). In general terms, the movement towards digital technologies is captured by those changes. A finer analysis could be done by focusing in specific cells: for instance, the height of biotechnology (OST 12) in 1991 was 7% of the leading peak, while in 2009 it grew to 27% of that peak - this could be an indication of new sectors emerging.

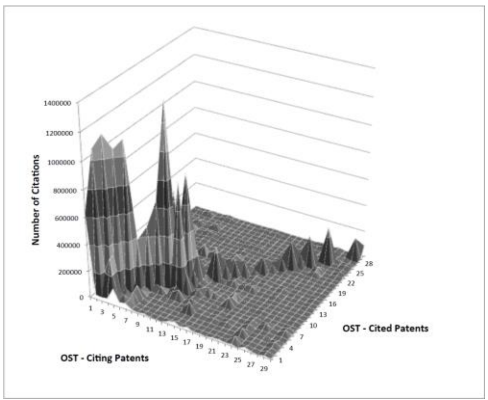
FIGURE 2
Dynamics of Intersectoral Change in Matrices of Citing and Cited Patents (1991, 2000 and 2009)
1991



2000



2009



Source: PATSTAT, authors' elaboration - See Appendix Table A.1 for OST Tecnological Subdomains.

Fourth, the leading OST subdomains in international citing patents (indication of absorption of knowledge) and cited patents (indication of diffusion of knowledge). In 2009, the leading OST subdomains for absorption (sectors in citing patents) are organic fine chemicals (OST 9), information technology (OST 4), pharmaceuticals (OST 11) and telecommunications (OST 3). The ranking of leading OST subdomains for diffusion (sectors in cited patents) are organic fine chemicals (OST 9), audiovisual (OST 2), information technology (OST 4) and telecommunications (OST 3).

This introductory analysis of those matrices shown in Figure 2 hightlights movements within this network over time. It also contributes to uncover in what directions this self-organizing system is moving, how it changes in the long term – probably a consequence of structural changes related to technological revolutions and the emergence of new general purpose technologies (GPTs) during those years.

V. NETWORK OF INTERNATIONAL PATENT CITATIONS, ITS PROPERTIES AND CONNECTIONS WITH OTHER NETWORKS

The contribution of this paper is the investigation of a network not investigated so far: its nodes are institutions, patent assigness - mainly firms as our analysis shows -, and its links are international or cross-border patent citations.

The database used by this paper provides data for the analysis of this network. This network of instituions linked by cross-border internation patent citations grows over time - in all dimensions -, is scale-free. Its pattern of growth shows that while it grows it preservers its structure, and this self-organized system over time changes the technological structure of its links.

The robustness of scale-free networks can be associated to the behavior of a complex system in the self-organized criticality state. This property reinforces the stability of cross-border links among institutions through patent citations, a knowledge flow with increasingly international characteristics. Therefore, to investigate innovation systems it is necessary to include this structure, this network of international flows. The robustness of this scale-free network stresses how firms (the institution most important in this networks) are dependent and reliant in those international flows. And how, for them, national boundaries are always overcome by their capacity to absorb foreign knowledge. Probably, one of the sources of this robustness is that to absorb knowledge, firms creates knowledge that diffuses globally.

Scale-free networks are hierarchical. The hierarchy in this firm-led network (power-law exponents aroud 2.05) is stronger that in the network of international scientific collaboration - a university-led network (power-law exponents around 1,73). To use this knowledge firms must perform R&D and to have internal capabilities to follow, to monitor and to understand the stock of knowledge accumulated in patents. Those prerequisites are not simple, and they are concentrated in a set of transnational firms with strong international presence (see Tables 2, 3 and 4).

This network of international flows is a source of opportunity, since the stock of patented knowledge is available to every institution in the world. Firms in less developed countries can access this knowledge, as new firms in developed countries. This stock of knowledge has been a source of transformation of old firms that may tap in this stock of knowledge to move into new and emerging systems. The stability, growth and robustness of this network suggest that the access to those international knowledge flows can be a goal in the planning of activities of firms, institutions and countries - innovation systems can be enriched by the access to those flows.

However, the hierarchical nature of this network poses great challenges to firms and instituions at the periphery and to new firms at the center. The preconditions to join this network are increasing, as the scientific and technological bases of new technologies expand. The stability of this network over time poses special challenges for institutions at the periphery. The database shows that the network grows over time - this means that more countries join the network, a process that broadens the set countries that may absorb and diffuse knowledge. The network also changes over time, expanding in different sectors in different moments, a process that may open new opportunities. Since 1991 this very hierarchical network involved a systematic upgrade of the position of two countries - South Korea and Taiwan, which are now among the five leading countries (Table 5) - and include an initial and sustainned upward movement of China, reaching the 19th position in 2009.

Implications for the generation and transfer of technology are straightforward: institutions - specially firms - to join this international network must be ready to both create and absorb knowledge. Cohen and Levinthal (1989) elaboration on the two faces of R&D finds other evidences in this database, as the major players in this network are leading both rankings of absorbers and of diffusers of knowledge.

At this stage of our research agenda on the emergence of an international innovation system, this paper identifies a second self-organized and robust *international* network, since in Ribeiro et al (2018) have presented a self-organized and robust network of international collaboration in science. Those two self-organized international networks have one important difference: they are self-organized around different key institutions - firms in the case of internationa patent citations and universities in the case of international collaboration in science. This difference might suggest a division of technological labor between those two international networks.

Those preliminary findings put forward a new question: are those networks isolated from each other or do they have connections?

Our initial answer suggests that there are at least two sources of connections between those two international networks. First, there is a specific international knowledge flow that connects them: an international flow between institutions (mainly firms) that patent and foreign institutions (mainly universities) that publish scientific papers. The channel of this international flow might be a citation in the patent to a scientific paper (Ribeiro et al, 2014). Ribeiro et al (2014) have not investigated whether those flows form a network, but those flows literally connect two international networks. Second, our research has shown that there are institutions that are part of both networks - IBM, a leading firm in the international network described in this paper is also present in the international network of international collaboration in science, as is the University of California, a leading university (Ribeiro et al, 2018). And both institutions are in the international flows that connect those two networks (the have patents that cite papers and have papers cited by those patents) (Ribeiro et al, 2014).

Other intersections can be described, as firms internationally co-author papers, universities have international patent citations, firms cite foreign scientific papers. Although those intersections and overlapings are an important subject of an agenda for further research, they migh be shaping innovation systems, as sources of that international factors that tension the national basis of innovation system, as Nelson and Rosenberg mentioned in 1993.

Starting from our tentative framework (Britto et al, 2013), our investigation on those flows uncovered that they are structured, that they form networks and that they evolve over time - meaning that they are more structured than we conjectured previously. As investigations on colaboration on scientific papers (Wagneer et al, 2005) and patent citations (Valverde, 2014; Érdi, 2016) discovered their network properties - self-organized systems - they contribute to understanding those international flows as layers of larger complex systems.

As in other complex systems, innovation systems are composed of different structures, different layers – and those constitutive structures (network of international scientific collaboration, network of international patent citations). As self-organized systems that are connected by diverse institutions and flows, they might be signalling new and broader processes behind the emergence of an international system of innovation. This paper can only point to this subject, suggesting further research on how those self-organized international systems connect, interact and might be aggregated in a broader complex system.

REFERENCES

ARROW, K. (1962) Economic welfare and the allocation of resources for invention. In: LAMBERTON, D. (ed). *Economics of information and knowledge*. Harmondsworth: Penguin Books, 1971.

ARROW, K. (1974) *The limits of organisation*. New York: W. W. Norton & Co..

ARROW, K. (1996) Technical information and industrial structure. *Industrial and Corporate Change*, v. 5, n. 2, pp. 645-652.

BARABÁSI, A-L; ALBERT, R. (1999) Emergence of scaling in random networks. *Science*, v. 285, pp. 509-512.

BRITTO, G.; CAMARGO, O. S.; KRUSS, G.; ALBUQUERQUE, E. M. (2013) Global interactions between firms and universities: global innovation networks as first steps towards a Global Innovation System. *Innovation and Development*, v. 3, n. 1, pp. 71-88.

BRITTO, J.; RIBEIRO, L. C.; ARAUJO, L. T.; MACHADO, G. T. M.; ALBUQUERQUE, E. (2019a) Knowledge flows, changing firms' competences and patent citations: an analysis of the trajectory of IBM. *Economics of innovation and new technology*, v. 28, n. 4, pp. 317-347.

BRITTO, J.; RIBEIRO, L. C.; ARAUJO, L. T.; ALBUQUERQUE, E. (2019b) Patents and catch up. Belo Horizonte: Cedeplar-UFMG (Textos para Discussão, forthcoming).

CANTWELL, J. (2009) Innovation and information technology in the MNE. In: RUGMAN, A. M. (ed.), *The Oxford Handbook of International Business*. Oxford University Press: Oxford, Second Edition, pp. 417-446.

CANTWELL, J. (2013) Blurred boundaries between firms, and new boundaries within (large multinational) firms: the impact of decentralized networks for innovation. *Seoul Journal of Economics*, v. 26, n. 1, pp. 1-32.

COHEN, W.; LEVINTHAL, D.A. (1989) Innovation and Learning: the two faces of R&D, *The Economic Journal*, v. 99, n. 397, September: pp. 569-596.

COHEN, M. D. AND LEVINTHAL, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. *Administrative Science Quarterly*, 35, 128-152

DUNNING, J.; LUNDAN, S. (2008) *Multinational enterprises and the global economy*. Cheltenham: Edward Elgar (Second edition).

ÉRDI, P.; K MAKOVI, Z. SOMOGYVÁRI, K STRANDBURG, J TOBOCHNIK, P VOLF; L. ZALÁNYI (2013). Prediction of emerging technologies based on analysis of the U.S. patent citation network. *Scientometrics*, v. 95, n. 1, pp.225-242.

ÉRDI, P. (2016). Patent citation network analysis: Topology and evolution of patent citation networks. In *Artificial Neural Networks and Machine Learning - 25th International Conference on Artificial Neural Networks, ICANN 2016, Proceedings* (Vol. 9886 LNCS, pp. 543). (Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial

Intelligence and Lecture Notes in Bioinformatics); Vol. 9886 LNCS). Springer Verlag. (10.1109/CompEng.2014.6994688)

GUELLEC, D.; POTTERIE, B. (2004) Measuring internationalization of the generation of technology: an approach based on patent data. In: MOED, H.; GLÄNZEL, W.; SCHMOCH, U. (eds). *Handbook of quantitative science and technology research*: the use of publication and patent statistics in studies of S&T systems. Dordrecht: Kluwer Academic Publishers, pp. 645-662.

HU, A. G. Z; JAFFE, A. (2003) Patent citations and international knowledge flows: the cases of Korea and Taiwan. *International Journal of Industrial Organization*, n. 21, pp. 849-880.

JAFFE, A. B.; TRAJTENBERG, M. (2002), *Patents, Citations, and Innovations*: A Window on the Knowledge Economy. Cambridge, MA/London: MIT Press.

JAFFE, A.; TRAJTENBERG, M (1999) International Knowledge Flows: Evidence from Patent Citations. *Economics of Innovation and New Technology*, v. 8, n. xxx, pp. 105-136.

KONECCT (2017) http://konect.uni-koblenz.de/networks/patentcite

NATURE (2019) Nature Index (http://www.natureindex.com/) (accessed 13 February 2019).

OBSERVATOIRE DES SCIENCES ET DES TECHNIQUES (2006). *Science & Technologie*: indicateurs 2006. Paris: Economica (http://www.obs-ost.fr/le-savoir-faire/etudes-en-ligne/etudes-2006/rapport-2006.html).

OECD (2013) Interconnected economies: benefiting from global value chains. Paris: OECD.

OECD (2015) *OECD Science, Technology and Industry Scoreboard 2015*: Innovation for growth and society, OECD Publishing, Paris. http://dx.doi.org/10.1787/sti_scoreboard-2015-en

PATEL, P.; PAVITT, K. (1998), National systems of innovation under strain: the internationalization of corporate R&D. SPRU: Brighton.

RIBEIRO, L. C. ; KRUSS, G. ; BRITTO, G. ; RUIZ, R. M. ; BERNARDES, A. T. ; ALBUQUERQUE, E. M. (2014) A methodology for unveiling global innovation networks: patent citations as clues to cross border knowledge flows. *Scientometrics*, v. 101, pp. 61-83.

RIBEIRO, L.; SILVA, L.; RAPINI, M.; BRITTO, G.; ALBUQUERQUE, E. (2016b) Mapping international knowledge flows: three dimensions for a framework to evaluate transnational cooperation in research. Paper presented at the conference *The Transformation of Research in the South: policies and outcomes* (Paris, 21 and 22 January 2016). Paris: IDRC/IRD/OECD Development Centre (http://ifris.org/wp-content/blogs.dir/1/files/2016/01/Eduardo-Albuquerque-MAPPING-INTERNATIONAL-KNOWLEDGE-FLOWS.pdf)

RIBEIRO, L. C.; RAPINI, M. S.; SILVA, L. A.; ALBUQUERQUE, E. (2018) Growth patterns of the network of international collaboration in science. *Scientometrics*, v. 114, p. 159-179.

ROSENBERG, N. (1990) Why do firms do basic research (with their money)? *Research Policy*, v. 19, pp. 165-174.

SILVA, L. (2014) Tensões e conexões: um estudo sobre multinacionais e sistemas nacionais de inovação. Belo Horizonte: Cedeplar-UFMG (Tese de Doutorado).

SOETE, L.; VERSPAGEN, B.; WEEL, B. (2010) Systems of innovation. In: HALL, B.; ROSENBERG, N. (eds) *Handbook of the economics of innovation*. Volume II. Amsterdam: North Holland.

STRANDBURG, K., CSÁRDI, G., TOBOCHNIK, J., ÉRDI, P., ZALÁNYI, L. (2009). Patent citation networks revisited: signs of a twenty-first century change? North Carolina Law Review, 87, 1657–1698.

VALVERDE, S. "Evolution of patent citation networks," *2014 Complexity in Engineering (COMPENG)*, Barcelona, 2014, pp. 1-5. doi: 10.1109/CompEng.2014.6994688

VALVERDE, S.; SOLÉ, R. V.; BEDAU, M. A.; PACKARD, N. (2007) Topology and evolution of technology innovation networks. *Physical Review E*, v. 76, pp. 056118.1-056118.7.

WAGNER, C.; LEYDESDORFF, L. (2005) Network structure, self-organization, and the growth of international collaboration in science. *Research Policy*, v. 34, n. 10, pp. 1608-1618.

WAGNER, C.; PARK, H. W.; LEYDESDORFF, L. (2015) The continuing growth of global cooperation networks in research: a conundrum for national governments. *PLOS one*, July 21, 2015

APPENDIX

TABLE A.1
LIST OF OST Technological subdomains

OST codes	OST names
1	Electrical components
2	Audiovisual
3	Telecommunications
4	Information technology
5	Semiconductors
6	Optics
7	Analysis, measurement and control
8	Medical engineering
9	Organic fine chemicals
10	Macromolecular chemistry
11	Pharmaceuticals and cosmetics
12	Biotechnology
13	Agricultural and food products
14	Technical procedures
15	Surface technology and coating
16	Material processing
17	Materials and metallurgy
18	Thermal techniques
19	Basic chemical processing
20	Environment and pollution
21	Machine tools
22	Engines, pumps and turbines
23	Mechanical components
24	Handling and printing
25	Agricultural and food machinery
26	Transport
27	Nuclear engineering
28	Space technology and weapons
29	Consumer goods and equipment
30	Civil engineering and building

Source: OST (2006)