TEXTO PARA DISCUSSÃO N° 463

UNVEILING GLOBAL INNOVATION NETWORKS

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Outubro de 2012

Ficha catalográfica

U61 Unveiling global innovation networks / Leonardo Costa Ribeiro
2012 ... [et al.]. - Belo Horizonte : UFMG/CEDEPLAR, 2012.
23 p. : il. - (Texto para discussão, 463)

Inclui bibliografia.

1.Empresas multinacionais. 2.Relações econômicas internacionais. 3.Inovações tecnológicas – Aspectos econômicos. I.Ribeiro, Leonardo Costa. II.Universidade Federal de Minas Gerais. Centro de Desenvolvimento e Planejamento Regional. III.Título. IV.Série.

CDD: 338.88

Elaborada pela Biblioteca da FACE/UFMG - JN 078/2012

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FACULDADE DE CIÊNCIAS ECONÔMICAS
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UNVEILING GLOBAL INNOVATION NETWORKS

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BELO HORIZONTE
2012

SUMÁRIO

ABSTRACT

The role of multinational enterprises in the internationalization of production has been recognized and studied from several points of view. We believe that multinational firms have a similar role in shaping flows of knowledge, technology, and scientific research. Therefore, multinational firms, science and technology could be linked in a way that allows us to identify Global Innovation Networks (GIN), another and important feature of the internationalization of capital. The goal of this paper is to develop a methodology to identify GINs, based on previous work on patents and their citations of scientific papers, which was adapted to track GINs. That is, the main indicators measure interactions between firms and universities. We argue that the links between patenting firms and the authors of cited papers establish connections that allow the identification of several types of GINs. A case study of IBM is presented in this paper, as a well-known leading patent firm with several papers cited in its patents. It may provide an excellent case to demonstrate how the selected indicators describe the knowledge flows between firms and research institutions. The conclusion shows that other GINs can be identified applying the same methodology.

Keywords: multinational firms, complex networks; diffusion; patents; innovation; technological change

RESUMO

O papel das empresas multinacionais no processo de internacionalização da produção tem sido objeto de estudo a partir de diversos pontos de vista. Acreditamos que as firmas multinacionais têm um papel similar na configuração dos fluxos de conhecimento, tecnologia e conhecimento científico. Assim, firmas multinacionais, ciência e tecnologia possuem podem ser conectadas de forma a permitir a identificação de Redes Globais de Inovação (GIN), outra característica importante do processo de internacionalização do capital. O objetivo desse artigo é desenvolver uma metodologia para identificar GINs a partir de uma complexa adaptação de trabalhos existentes sobre patentes e a citação de artigos científicos. Argumentamos que as conexões entre firmas patenteadoras e os artigos citados nessas patentes representam conexões que permitem a identificação de tipos diferentes de GINs. Além da metodologia e resultados gerais, um breve estudo de caso da IBM é apresentado para demonstrar como os indicadores selecionados descrevem os fluxos de conhecimento entre firmas e institutos de pesquisa. Em função dos resultados apresentados argumentamos que a metodologia pode ser utilizada para identificar uma grande variedade de GINs.

Palavras-chave: firmas multinacionais, redes complexas, difusão, patentes, inovação, mudança tecnológica.

JEL: 030

Acknowledgements: research for this paper was partially funded by CNPq, CAPES and Fapemig. The authors are thankful for the research assistance from Marcelo de Brito Brandão.

INTRODUCTION

The internationalization of capital has changed international technological flows. Multinational Enterprises (MNEs) are key drivers of these changes: they shape and reshape the global industrial and technological landscape. These changes are deep enough to indicate a "new era of innovative capitalism", as Cantwell proposes (2008, p. 437). The author describes a shift in the role of MNEs, from drivers of technology transfer in forms that were typically replicated in each location. MNEs are increasingly drivers of international networks that create technology, by connecting the 'streams of innovation' taking place in each location, and reorganizing as they internationalise them. In this new era, interactions between universities, research institutes and firms become increasingly internationalized, giving rise to "global innovation networks" (Ernst, 2006; OECD, 2007).

However, the challenge remains to measure the extent and location of these changes and shifts. This paper presents one methodology to identify the emergence of global innovation networks (GIN), through investigating the interactions taking place between firms and universities at the global level. Our methodology is based upon previous work that tracked flows between firms and universities by analysing USPTO patents and their citations of ISI-indexed scientific papers (Ribeiro et al, 2010). That methodology is adapted to track flows between firms and universities that are part of broader global innovation networks (GINs).

We have built a database to investigate these networks and to analyse the flows identified. The database was prepared from 167 315 USPTO patents granted in 2009, of which 86 652 had non-patent references such as scientific papers and manuals. Of those, a total of 22 577 patents that cited ISI-indexed papers were identified. The links between these patenting firms and the authors cited in ISI-indexed scientific papers are used to establish the basis for analysing knowledge flows in this paper.

I - MNES AND "STREAMS OF INNOVATION"

GINs have two main drivers. First, there are MNEs and their growing capabilities, technological and locational diversity, as they move across the world selecting locations and distributing productive and innovative labour. Second, the formation and growing complexity of national systems of innovation (NSIs), especially at the periphery, is a process that goes far beyond the limited push of capital towards new regions and sectors. An important engine of this process is the internationalization of science. The formation of NSIs involves political forces that shape states and their autonomy, capabilities and public resources to generate and support public institutions. For example, the rise of talent pools is a consequence of investments in science and engineering that shape NSIs. Therefore, there are two movements reshaping and reorganizing the international division of labour. This reshaping of the international division of labour, in turn, affects the internal decisions of MNEs and the actions of their subsidiaries, pushing further changes in the international division of innovative labour.

The combination of these two drivers leads to a complex picture, where the nature of NSIs matters for the formation of innovation networks, their main characteristics and the nature and scope of the international hierarchies established. Firms - local and MNEs - universities and their links, are reflected in a hierarchical world, divided between a center and a periphery (Furtado, 1982), and the implicit social and political forces that shape the NSIs defining the major countries' characteristics and possibilities within a global innovation system in the making.

Extending this interpretation of the drivers of GINs, and drawing on an analysis of key strands in the literature, we developed a framework to analyse the globalization of interaction between universities and firms (Britto et al, 2011). The main contributions that underpin the logic of the framework are summarized briefly here.

The starting point for our framework was the literature that conceptualizes the interactions between firms and universities in developed countries, typically focused on interactions within a single country (Klevorick et al 1995, Cohen et al 2002). This work has been elaborated to examine the interactions between firms and universities in developing countries, again, interaction within national boundaries, but which may include MNEs' subsidiaries in those countries (Rapini et al, 2009, Lee et al, 2009, Kruss, 2009).

A similar limited set of interactions are suggested by Patel and Pavitt (1998), who stressed the ways in which firms in developed countries may use other countries' scientific infrastructure as sources of information, where national systems are not able to meet the needs of innovating firms.

A critical work that shifted attention to internationalization of interaction is an UNCTAD (2005) study that demonstrated the chain of MNE connections between developed and developing countries. Ernst (2009) built a taxonomy of GINs that further informed our elaboration of these connections. Ernst proposed type 1 and 2 GINs, in which MNEs based in a developed economy either 'offshore' or 'outsource' aspects of innovation to firms, subsidiaries or other affiliates, including universities, in developing economies. Ernst's (2009) elaboration of a type 3 GIN, of a MNE based in a country at the periphery interacting with universities and research institutions at the center, informed the elaboration of the framework (see also Azevedo 2009). OECD (2008b) research on Japanese MNEs and their networks with universities in China, India, Japan and the US illustrated a different set of possible connections between MNE headquarters, MNE subsidiaries (including in the US) and universities.

The literature also highlighted a growing trend towards connections between firms based in different countries at the periphery, for instance, biotechnology inter-firm networks (Thorsteinsdóttir 2010). Those firms were typically born as spin-offs of local university research with their international connections.

The significance of connections between universities only – science networks – was also included in the framework. There are strong "engines of internationalization" of science, old and new (Zitt et al 2004). For developing and catch up countries, the networks of science and related educational investments may be the first networks established to connect one country with the global knowledge networks based in the leading countries. Examples are global research consortia such as the *International Human Genome Sequencing Consortium*, with research institutes from the US, China, France, Germany, Japan participating. The important of these scientific networks should not be underestimated.

Drawing on these distinctions in the literature, a framework was developed that yields four main types of university-firm interaction, with variations depending on their location in the centre or periphery. These types necessarily go beyond GINs, both backwards and forwards.

TYPE 1: ONLY LOCAL INTERACTIONS. These are interactions between local firms and local universities. This type does not involve cross-border transfer of knowledge. It could represent the first step for a firm to become transnational. That is, it allows for an initial accumulation of knowledge and capabilities that supports a transition from being a local to a transnational firm, since there is a deep correlation between transnationality and R&D-intensity (Caves, 1996). In earlier stages of capitalism at the center, they would have been the typical and most advanced interactions with universities. Now, this type of interaction may be located in firms at the periphery.

Interactions between local firms and foreign universities are the first and simplest form of cross-border transfer of knowledge. Local firms would typically interact both with universities in their home countries and with foreign universities. Historically, this type would have first connected developed countries. Currently, this type of interaction would be important for local firms at the periphery looking for knowledge that the local science infrastructure would not be able to provide.

TYPE 2: TRANSNATIONALS INTERACTING ONLY WITH HOME COUNTRY UNIVERSITIES. This would be the typical relationship reported in the literature on internationalization of R&D. The MNEs have connections with their home country universities, but the host countries either do not have R&D activities or the R&D activities are completely centralized at the MNE headquarters.

TYPE 3: TRANSNATIONALS INTERACTING BOTH WITH HOME COUNTRY AND HOST COUNTRY UNIVERSITIES. This would be the more recent pattern of interaction. There is a broader division of innovative labour within the MNE, with the possibility that a subsidiary assumes contact and performs contracts with the host country university. The nature of this relationship will depend on the nature of the subsidiary's role within the MNE, ranging from limited adaptive activities – that would require contacts with local laboratories or engineering departments – to more advanced projects – that would involve R&D joint research with local universities, sometimes in connection with foreign universities too. The hierarchy and the decision-making about the specific roles of home-country and host countries R&D departments may vary deeply, and the variety is incorporated within this type.

Firms (local or transnational) may establish contact with one specific university (local or foreign) but would take advantage of the other universities (local or foreign) that are linked to the first university through their existing scientific and educational links. This is important, given the natural trend to the internationalization of science, with its formal and informal links. The interactions of firms with networks already established among universities are rich in multidirectional knowledge flows.

TYPE 4: INTERNATIONAL CONSORTIA BETWEEN FIRMS AND UNIVERSITIES. This type involves firms, universities and research institutions, but they might be proposed and coordinated by the academic side of the interaction. Intergovernmental cooperation and international institutions, such as WHO, could trigger this kind of interaction. They could be “mission-oriented” and necessarily non-hierarchical. They also could be a characteristic of a global innovation system.

A fifth type is possible, but not yet existent – a non-hierarchical network between MNE headquarters and subsidiaries and their connections with universities. Asymmetry and hierarchy are “defining characteristics of both previous GPNs and existing GINs” (Ernst, 2009). This type must be included to benchmark prevailing international networks. It could be seen as the desired feature of a global innovation system, and poses a challenge to policy.

The four main types elaborated in terms of this conceptual framework attempt to summarize the full range of interactions, but they certainly do not cover all possibilities. Many real world cases would be mixed cases. For example, we may find the formation of international networks that combine interactions at MNE headquarters that have interfirm connections with local firms in a foreign country, and this local firm may have interactions with local universities. Another example is a MNE that establishes contacts with foreign universities either in countries where it does not have a subsidiary or directly with a foreign university, bypassing its local subsidiary. The following section will use this conceptual framework to map the connections between “streams of innovation” at the centre and periphery.

II- METHODOLOGY

The methodology developed to map these connections is an extension of an earlier methodology to map interactions between local firms and universities only, as presented in Ribeiro at al (2010). In that study, we developed a methodology and software for collecting information on patents granted in the USPTO (www.uspto.gov). The first step adapted for the present work was to use the software to search and download a set of information for all patents granted in the year 2009:

1) USPTO patent number
2) First inventor's country (if from the USA, the first inventor's state)
3) Assignee's name
4) Assignee's country (if from the USA, the assignee's state)
5) Application date
6) Issue date
7) USPTO patent number of each cited U.S. patent
8) Other references cited by the patent (these are the non-patent references)
9) U.S. classification code (class and subclass).

For the new analysis of all types of interaction developed in this paper, the next step was to focus on the non-patent references (scientific articles and manuals, for instance). Thereafter, we split the text of each reference into four parts: authors, title, journal, and other information. Using specially created software, the data on title and journal was used to search and identify the article on the Institute for Scientific Information (ISI) site. Once the article was located, the software collected the following information: 1) Title; 2) Authors’ institutional address; 3) Source; 4) Publication date; 5) Publisher; 6) Web of science category; 7) Subject category; 8) ISSN; 9) DOI.

Using these datasets, we then prepared two lists of firms and institutions: one with all patenting firms in 2009, and another with all the institutions that authored the papers cited in 2009. The institutional authors were classified as either MNE headquarters, MNE subsidiary, Local Firm or Research Institution. To classify the firms, we used available lists such as Global Fortune 500, UNCTAD, and institutional websites.

Then, we were able to connect a patenting firm, located in a specific country, with the research institute, university or even the firm that had authored the paper cited in the patent application. These linkages are the key relationship investigated in this paper. Therefore, our database and methodology are tools to empirically verify the existing scale and nature of global interactions between firms and research institutions.

The literature on interaction between firms and universities (Klevorick et al, 1995; Cohen et al, 2002) indicates the multifarious channels of knowledge flow that run both ways: publications, informal exchange, consultancy, hiring of recent graduates, conferences or cooperative research. In the case of the US, publications are ranked in first place as the main “channel of interaction” (Cohen et al, 2002, p. 15). In the case of a peripheral country such as Brazil, publications and reports are also ranked in first place (Fernandes et al, 2010, p. 491). This methodology therefore captures only one – but a very significant - feature of global interactions between firms and universities. It is based on those interactions represented by codified knowledge, as documented by patents, and only the formal channels between firms and universities, as represented by the scientific publications cited by those patents. Those channels are interpreted here as proxies of broader relationships, but they are sufficient for the purposes of this investigation, to provide strong empirical evidence of global links.

To understand the scope of our preliminary results, descriptive statistics provide a general picture.

Table 1 shows the country distribution of patents and cited papers. The leading position of the USA, Japan and some European countries is immediately evident. Regarding the total number of patents, the position of catch up countries like South Korea and Taiwan (in fourth and fifth positions) and China (in ninth position) can be highlighted. India lies in the 17th, Brazil in the 29th and South Africa in the 30th position.

Regarding the total number of cited papers, the leading positions of USA, Japan and Germany are preserved, but China (in the sixth position) overtakes South Korea and Taiwan, while India and Brazil fall to the 24th and 44th positions, respectively.

TABLE 1
Country distribution of patents and cited papers (2009)

	Country Distribution of Patents		Country Distribution of Cited Papers	
	Country	Patents	Country	Cited Paper
1	USA	74068	USA	17671
2	JP	35312	JP	879
3	DEU	8709	DEU	652
4	KR	8577	GBR	617
5	TW	5804	CAN	418
6	CAN	3181	CH	269
7	FR	3052	FR	192
8	GBR	3018	SE	186
9	CN	1633	NL	153
10	IRL	1303	IRL	131
11	NL	1262	KR	126
12	IT	1221	IT	119
13	CH	1169	AU	105
14	AU	1123	ES	87
15	SE	979	BE	80
16	FI	829	TW	79
17	IND	657	NZ	76
18	BE	575	DK	74
19	AT	467	CN	45
20	SG	420	FI	41
21	DK	372	RU	32
22	ES	293	AT	29
23	NO	248	TR	27
24	IE	169	IND	27
25	RU	160	HK	27
26	HK	157	NO	24
27	MY	154	SG	15
28	NZ	112	ARG	13
29	BR	85	LV	12
30	ZA	74	ZA	12
31	MX	48	IE	10
32	CZE	39	PT	8
33	HU	39	IR	7
34	LU	36	SI	6

Source: USPTO, authors' elaboration

Table 2 describes the leading patenting firms, as well as the leading patenting firms with non-patent references (scientific paper citations are one of the non-patent references).

TABLE 2
Leading patenting firms (2009)

Patenting Firms Ranking			Patenting Firms Ranking (only patents citing NPR)		
Firm	Country	Patents	Firm	Country	Patents
IBM	USA	3947	IBM	USA	2128
Samsung Electronics Co. Ltd.	KR	3015	Microsoft Corporation	USA	2100
Microsoft Corporation	USA	2612	Samsung Electronics Co.	KR	1321
Canon Kabushiki Kaisha	JP	2094	Panasonic Corporation	JP	926
Panasonic Corporation	JP	1675	Kabushiki Kaisha Toshiba	JP	837
Kabushiki Kaisha Toshiba	JP	1574	Canon Kabushiki Kaisha	JP	826
Sony Corporation	JP	1504	Intel Corporation	USA	806
Intel Corporation	USA	1308	Sony Corporation	JP	638
Seiko Epson Corporation	JP	1230	Fujitsu Limited	JP	628
HP Dev. Company L.P.	USA	1105	HP Dev. Company L.P.	USA	589
Fujitsu Limited	JP	1095	Cisco Technology Inc.	USA	558
LG Electronics Inc.	KR	1026	Micron Technology Inc.	USA	547
Hitachi Ltd.	JP	983	LG Electronics Inc.	KR	494
Micron Technology Inc.	USA	880	Hitachi Ltd.	JP	464
General Electric Company	USA	835	Semiconductor Energy Lab	JP	418
Cisco Technology Inc.	USA	780	Seiko Epson Corporation	JP	404
Ricoh Company Ltd.	JP	726	Ricoh Company Ltd.	JP	392

Source: USPTO, authors' elaboration

Firms related to the present technological paradigm are ranked in the leading position, in accordance with our earlier findings. Thus, the main peak in our matrices of science and technology interactions was in the matrix cell “information technology” X “electronic engineering” (Ribeiro et al, 2010). Here too, the leading patenting firms are IBM, Microsoft, Samsung, Panasonic and Siemens. The leading role of IBM in both columns of Table 2 is evident. Only firms from USA, Japan, South Korea and Germany are in the 20 first positions.

Table 3 presents the other side of these global interactions: the leading institutions that authored the papers cited in those patents. The leading position of USA universities is predominant: there are only four non-US universities within the 43 leading institutions listed in Table 3, and these institutions are from England, Israel and Japan.

TABLE 3

Ranking of Cited Institutions (2009)

Cited Papers' Institution Ranking				
	Institution	Type	Country	Cited Papers
1	HARVARD UNIV	RI	USA	1569
2	MIT	RI	USA	711
3	STANFORD UNIV	RI	USA	683
4	UNIV TEXAS	RI	USA	613
5	UNIV CALIF SAN FRANCISCO	RI	USA	436
6	NCI	RI	USA	434
7	UNIV WASHINGTON	RI	USA	387
8	UNIV CALIF BERKELEY	RI	USA	385
9	UNIV CALIF SAN DIEGO	RI	USA	354
10	UNIV PENN	RI	USA	340
11	JOHNS HOPKINS UNIV	RI	USA	331
12	WASHINGTON UNIV	RI	USA	320
13	CORNELL UNIV	RI	USA	313
14	GENENTECH INC	MNE-S	USA	309
15	YALE UNIV	RI	USA	294
16	MASSACHUSETTS GEN HOSP	RI	USA	286
17	UNIV MICHIGAN	RI	USA	286
18	CALTECH	RI	USA	285
19	UNIV CALIF LOS ANGELES	RI	USA	275
20	DUKE UNIV	RI	USA	269
21	SCRIPPS RES INST	RI	USA	260
22	UNIV MINNESOTA	RI	USA	226
23	UNIV WISCONSIN	RI	USA	221
24	MEM SLOAN KETTERING CANC CTR	RI	USA	213
25	IBM CORP	MNE-H	USA	205

Source: USPTO, authors' elaboration

Table 3 reflects that two USA firms are leading authors of cited papers (Genetech and IBM). Genetech, the pioneering firm in the biotechnology sector is in the fifth position – and is not in the current leading technological paradigm. The presence of IBM as the 25th leading author of cited papers is also noteworthy, since IBM is the only firm that is present both in Table 2 and Table 3.

These preliminary descriptive statistics present the general context from which our detailed analysis begins: the identification of firms, institutions and their locations. This database provides us with data to track the flows and "streams of innovation" between firms, institutions and locations.

III- IBM AS A CASE

IBM is an excellent starting point for an illustrative description of our database and methodology. As the leading patent firm, as reflected in both columns of Table 2, and as one of the firms that have papers cited in patents, as shown in Table 3, this global firm may provide an excellent case to see how our data can describe flows between firms and research institutions. Furthermore, IBM was a firm highlighted in a pioneering paper by Narin et al (1997), which described how IBM used scientific information from domestic and foreign sources.

Table 4 summarizes flows from IBM headquarters and subsidiaries, and their use of scientific information provided by papers from different countries.

TABLE 4
IBM Streams of Innovation from headquarters to subsidiaries

IBM "Streams of Innovation" Sample				
Patent Country	Cited Paper's Institution	Type	Cited Paper Country	Cited Papers
USA	MIT	RI	USA	13
USA	IBM MICROELECT	MNE-H	USA	10
USA	IBM CORP	MNE-H	USA	8
USA	PRINCETON UNIV	RI	USA	6
USA	AUBURN UNIV	RI	USA	5
USA	POLITECN MILAN	RI	ITALY	5
USA	GEORGIA INST TECHNOL	RI	USA	4
USA	SIEMENS AG	MNE-H	GERMANY	4
USA	CORNELL UNIV	RI	USA	3
USA	DELFT UNIV TECHNOL	RI	NETHERLANDS	3
USA	SIMON FRASER UNIV	RI	CANADA	3
USA	STMICROELECT	LF	ITALY	3
CH	ETH HONGGERBERG	LF	SWITZERLAND	1
CH	IBM RES GMBH	MNE-S	SWITZERLAND	1
CH	MIROMICO AG	LF	SWITZERLAND	1
CH	PAUL SCHERRER INST	RI	SWITZERLAND	1
CH	WASHINGTON UNIV	RI	USA	1
JP	QUEENS UNIV BELFAST	RI	IRELAND	1
NZ	IBM CORP	MNE-H	USA	1
NZ	SUMITOMO ELECT IND LTD	LF	JAPAN	1

Source: USPTO, authors' elaboration

The first column shows the location of the specific IBM unit: there are patents from the USA headquarters and from subsidiaries located in three foreign countries – Japan, Switzerland and New Zealand.

The second column shows the institution that authored the paper cited by those patents, the third column the nature of that institution (a research institute, a local firm or a MNE - headquarter or subsidiary), the fourth column the country of this institution, and the last column the number of citations received by papers from that specific institution.

Thus, Table 4 demonstrates a wide range of international flows, linking a USA branch of IBM citing papers from developed foreign countries such as Switzerland, Japan, Germany, France, England, Netherlands, Israel, Belgium, Portugal, catch up countries such as South Korea and Taiwan, developing countries such as India and China, and transition countries such as Czech Republic and Romania. An IBM subsidiary located in Switzerland cites papers from local institutions and from the USA. The Japanese subsidiary cites an Irish research institution, and the subsidiary from New Zealand cites research institutions from USA and Japan.

There are not only universities cited, but also firms. IBM patents cite papers authored by firms like IBM itself, USA firms like Eaton Corp and Infineon Tech. Corp, Japanese firms like Sumitomo Elect. Ind. Ltd, Sony Corp. and Toshiba Corp. In sum, analysis of the data in Table 4 demonstrates that IBM has flows that connect it with research institutes, MNE headquarters and subsidiaries, and with local firms.

Table 4 thus provides a picture of the scope of the links organized by IBM globally. It provides a strong indication of the capability of this MNE to absorb knowledge generated all over the world, a tremendous flexibility probably not available to smaller global corporations.

Table 4 illustrates that our methodology can offer the kind of picture we are looking for – to identify connections between firms and universities, and firms and firms that cross national frontiers. Global interactions may be captured by this methodology.

IV- GLOBAL INTERACTIONS BETWEEN FIRMS AND INSTITUTIONS

The case of IBM is but one detailed example, and it represents Type 3, only one of the four types of the taxonomy presented above.

Once our methodology has been illustrated for a single corporation and its global flows indicated, and once we have demonstrated examples of all types of our taxonomy, we may proceed to the next step of our inquiry: to aggregate those flows by country or region. As an illustrative example of the possible aggregation, this section presents data for the USA in Table 5. Then, we summarizes indicators prepared using similar data generated for 7 countries or regions in Table 6. Those data are the basis for a map that graphically expresses global innovation networks.

Table 5 describes the data for USA. Patenting firms located in the USA cite papers authored in 73 different countries. This is a first indication of how widespread the networks that originate in the USA are.

TABLE 5

Streams of Innovation by country

USA "Streams of Innovation" Sample					
Cited Paper Country	Institution Frequency	RI Frequency	MNE-H Frequency	MNE-S Frequency	LF Frequency
USA	22169	17814	967	459	2929
JAPAN	2076	1579	101	84	312
GERMANY	1361	1162	18	57	124
ENGLAND	1265	1080	12	52	121
FRANCE	1107	838	40	22	207
CANADA	985	909	0	7	69
ITALY	697	549	5	16	127
SWITZERLAND	579	397	10	35	137
NETHERLANDS	532	470	8	6	48
ISRAEL	432	376	0	6	50
SWEDEN	427	382	0	12	33
AUSTRALIA	311	259	0	0	52
BELGIUM	294	254	0	18	22
SOUTH KOREA	268	247	1	5	15
SPAIN	264	196	0	2	66
TAIWAN	245	237	0	0	8
CHINA	236	233	0	2	1
AUSTRIA	218	208	0	2	8
FINLAND	199	178	0	2	19
DENMARK	169	137	4	2	26
SCOTLAND	119	104	0	0	15
RUSSIA	102	97	0	0	5
INDIA	97	92	0	0	5
NORWAY	75	66	0	0	9
POLAND	67	65	0	0	2
BRAZIL	50	48	0	0	2
IRELAND	47	46	0	0	1
SINGAPORE	47	45	0	0	2

Source: USPTO, authors' elaboration

Table 5 shows that patents from USA-based firms have 34 885 citations from papers produced by research institutes and firms. This data highlights the overall size of the knowledge flows that ground the innovations codified in the patents. USA-based patenting firms cite mostly USA-authored papers (22 169 citations - 64% of those citations - are from domestic sources). Those 22 169 domestic citations are from 2 317 different institutions, mostly from research institutions – 17 814 citations, originated in 1 141 different research institutions. The importance of other sources may be grasped by the number of citations of papers authored by firms – 2 929 by local firms (non-MNE firms), 967 by

MNE headquarters and 459 by MNE subsidiaries (respectively from 943, 178 and 55 and firms. More citations arise from papers authored in the MNE headquarters than the subsidiaries.

The second source of citations is Europe, and Japan is the third source. For those two locations, all kinds of institutions are cited (research institutions, local firms, MNE headquarters and subsidiaries).

Table 5 organizes the relevant data for the evaluation of international networks based on patenting firms. The USA case is useful because it has a broad global network, spanning all continents and including all different sources.

A comparison of other countries and regions with the USA case is organized in Table 6, which summarizes the indicators for the flows by country or region.

TABLE 6
Descriptive statistics of selected GINs

Home country	Countries cited	Instit. Freq.	RI Freq.	MNE-H Freq.	MNE-S Freq.	LF Freq.	Domestic Citations.	Foreign Citations.
USA	73	34885	28471	1166	796	4452	64%	36%
EUROPE	54	3823	3108	105	79	531	39%	61%
JAPAN	40	1634	1261	74	44	255	26%	74%
CHINA	16	78	63	1	4	10	6%	94%
INDIA	10	57	51	0	1	5	2%	98%
SOUTH AFRICA	18	45	43	0	1	1	0%	100%
BRAZIL	6	10	6	0	0	4	0%	100%

Source: USPTO, authors' elaboration

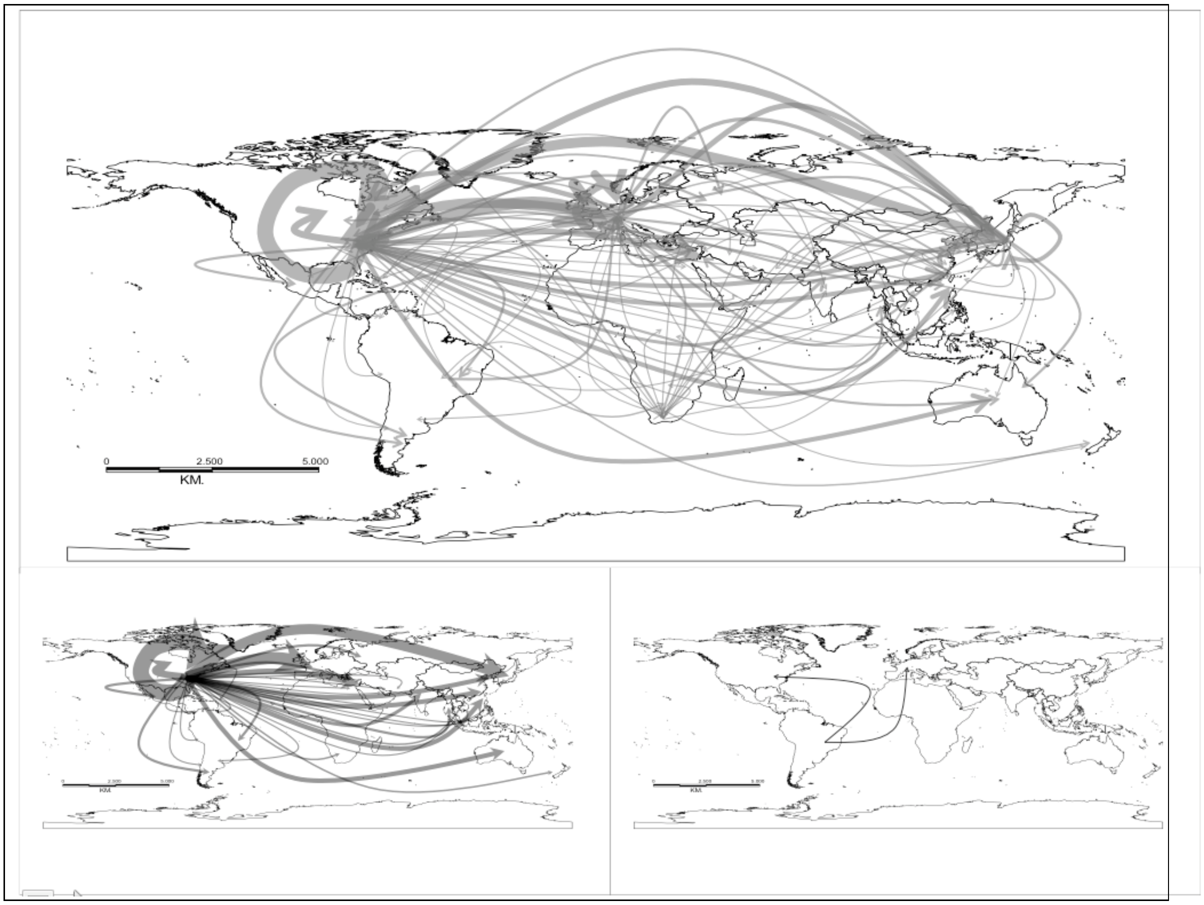
Table 6 shows that USA has the largest global base of international networks - 73 countries are the source of paper citations. It is followed by Europe as a region - citing 54 countries - and Japan - citing 40 countries. Countries representing the South (China, India, South Africa and Brazil) cite less, and correspondingly fewer countries are sources of the citations of their patents.[1] The North-South divide in the size of flows is clear, as measured by the total of institutional citations - all four of these countries have less than 100 institutional citations.

Domestic sources are more than half of the total of institutional citations only in the USA case. Europe and Japan have flows originating domestically for around approximately 30% of their institutional citations. Although fewer than the USA case, they have a very different pattern than the four countries from the South - for instance, not more than 6% of citations are from domestic sources in the case of China. This may be an indication of the importance of foreign sources for immature NSIs. Public policies to strengthen the size and quality of local science and technology infrastructure are required, if over time their NSIs are to improve.

[1] The size of the flows for the USA is in line with our findings in a previous paper (Ribeiro et al, 2010 - Scientometrics). The data presented in that paper show that the USA patents have a higher propensity to cite papers and reports. Therefore there is a gap between the total of USA institutional citations and the rest of the world, even Europe and Japan.

Finally, the data is the source for a map that expresses and illustrates international flows graphically (Figure 1).

FIGURE 1
Global Streams of Innovation



Source: USPTO, ISI, authors' elaboration

Note: Above: global flows of interactions.
Below, left: USA's flows of interactions.
Below, right: Brazil's flows of interactions

The map summarizes data as presented in Table 5 for the USA, aggregating similar information from Europe, Japan, China, India, South Africa and Brazil. As an example of the process of preparation of a map, the maps for USA and Brazil are included for contrast. They illustrate the most internationally connected and the least internationally connected countries in our sample, and thus are intended to help the reader to understand how Map 1 aggregates the flows.

Figure 1 contributes to our investigation in two ways. First, it shows how the different types of the taxonomy suggested above compose a global picture. Second, it expresses graphically the persistence of strong hierarchies in the global scientific and technological scenario - a renewed warning of the international cooperative measures required to soften the prevailing North-South divide.

V- CONCLUSIONS

Global innovation networks are a new phase in the internationalization of MNE R&D and may be seen as first steps towards a global innovation system. Of course there are a lot of steps between the very rudimentary GINs and even the beginnings of a global innovation system.

The typology suggested in this paper focuses on one feature of GINs: the global interactions between firms and universities. The literature review showed how diverse strands of the literature deal with this important feature of GINs. Based on three strands the paper suggested a very simple typology that helps to organize the empirical investigation of flows related to GINs.

The paper is an attempt to track those flows empirically, tracing a relationship described by the investigation of the patent citations of scientific papers - a research avenue opened by Narin et al (1997). We are aware that those flows are only part of a very broader picture. There are relationships between firms and firms (that may be investigated by patent citations of patents), there are relationships between universities and universities abroad (through co-authorships and through students and researchers visiting other universities), and there are relationships between MNE HQ and MNE subsidiaries through visits and co-operation between engineers and researchers from different units.

The flows described in this paper hint how widespread those interactions are, even in a formalized way as reflected through analysis of the papers cited by patents. The flows describe a general picture of increasing interdependence between countries. They confirm findings from Narin et al (1997) that have shown how a global firm like IBM benefited from research globally. And our data showed how widespread these global networks are amongst leading global firms.

The methodology and data presented in this paper help to organize the investigation of GINs.

First, it ranks countries according to their involvement in GINs (Table 1). There are 96 countries with USPTO patents with NPR (14 with more than 1,000 patents), but only 46 countries generating papers cited by those patents (13 with more than 100 papers). This distribution points to a concentration of knowledge flows among a limited number of countries.

Second, it ranks both firms and research institutions according to their patents and paper citations. Again, there is a strong concentration: 1) there are 20 425 different firms with patents with NPRs, but only 12 firms with more than 500 patents; 2) there are 6 768 institutions that produced cited papers, but only 4 with more than 500 cited papers.

Third, it shows how IBM, with divisions patenting from 4 different countries, cites papers produced in 93 different institutions (including firms like IBM and Toshiba), from 20 different countries. MNEs are also truly global learning machines.

Fourth, it shows how different GINs are. The indicators suggested in section 5 disaggregate the GINs into at least three different categories: the North may be divided into two categories, one for the USA and the other for Europe and Japan; and the South forms a third category.

Finally, the description of the unequal distribution of flows, as summarized in Figure 1, provides a starting point for an agenda to build a global innovation system.

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