A network analysis of cities hosting ICT RD

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Abstract

We apply network analysis to study the ICT R&D locations at the city level. We use a dataset on the location and R&D activity of over 3000 R&D centres belonging to 175 MNEs, located in over 1300 cities around the world. The results show that most of the cities have few R&D connections and are grouped into "cliques", linked through network hubs. Hence, not only is the R&D activity concentrated in space, but also the nexus of connections between locations is limited. Asian and Japanese cities are favoured as a source of R&D services, as compared to European or US cities.

1. Introduction

As a result of multinational enterprises' (MNEs) decisions concerning the location of their R&D activities, a global R&D network is emerging (Kali and Reyes 2007; Sachwald 2008; Lahiri 2010; Nieto and Rodriguez 2011). An important implication of this process for both MNEs and locations of R&D activity is that being connected globally is increasingly recognized as crucial determinant of the position of individual MNEs and locations in the global hierarchy (Cantwell and Janne 1999; Meyer, Mudambi et al. 2011).

Taking into account the existing gap in treating the globally dispersed R&D activity as a system of inter-lined activities and accounting for the heterogeneity of locations, the present work applies network analysis to study the interplay between network positions of cities hosting ICT R&D activities. A natural way of constructing an R&D network is by drawing a line between each pair of cities that share an R&D centre through a location and ownership relationship. This way we illustrate the destination and the source

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of R&D services MNEs are procuring from various locations around the world. By doing this for all the cities owning and hosting R&D centres, we are able to create a unique map of R&D service flows between cities, i.e. the global network of R&D locations.

The application of network analysis to study R&D locations is motivated by the fact that the increasing internationalisation of R&D activities, the notion of the knowledge stickiness and the resulting emergence of connections between various places around the world let us believe that firms' R&D location choices together with the characteristics of locations create externalities and that they mutually affect each other (Dunning 2009; Enright 2009).

We aim at answering a few layers of questions. First, what is the structure of the global network of R&D locations? Second, what are the workings of network interactions? Third, what positions cities occupy in this network? By answering the extensive list of questions, we were aiming at casting some more light on the issues of MNEs choices with respect to R&D location decisions and their implications for cities.

2. Data

The analysis is based on a unique dataset that contains information on the location and ownership of over 3000 R&D centres belonging to 175 MNEs which, in 2011, were located in over 54 countries and over 1300 cities around the world. The data used in this paper originates from the 2011 JRC-IPTS R&D Internationalization Database, a company-level dataset dedicated to observe the internationalization of ICT R&D. It includes a list of R&D centres belonging to a number of high-tech companies together with their exact location and additional information on the type of R&D activity performed in these centres. The data on R&D locations was collected by iSuppli, an industry consultancy,[2] with the aim of mapping R&D locations and activities of companies considered as the major semiconductor influencers, i.e. the main users of semiconductors or, in other words the largest manufacturers of applied electronic and microelectronic products. In order to check how representative the sample is, we compared it to the R&D Scoreboard, a list of top 2000 R&D investors in Europe and the rest of the

2 http://www.isuppli.com

world[3], and the list of companies filing their patents at the USPTO. The results of this checks revealed that the firms contained in the dataset represent nearly 30% of the 2008 R&D budget of all companies included in the R&D Scoreboard and more than 30% of all patent applications filed to the USPTO in 2009. This way we are assured that the sample is representative for the population of large high-tech multinational firms. Even if the characteristics of the dataset do not allow for building time series and, the dataset itself represents a unique collection of data for its coverage with a great level of details provided.

Table 1 displays the distribution of companies by their sector of main activity together with the number of R&D centres belonging to each sector. The first five sectors account for over 50% of the sample in terms of both the number of firms and the number of R&D centres. Nevertheless, the majority of sectors dominating the sample can be described as high-tech industries in which technological competition and the world-wide quest for knowledge resources determine companies' internationalisation strategies.

According to Table 2, all these companies own over 3,200 R&D centres in 54 countries in and 1345 cities worldwide. Altogether, there were 2535 links between these cities, meaning that the average strength of a link between two cities was close to 2 or, in other words, on average a pair of two cities was linked by means of two connections, i.e. two R&D centres.

3 http://iri.jrc.ec.europa.eu/research/scoreboard_2010.htm

Table 1. Distribution of companies' activities, by ICB classification

Nr	ICB sector	Nr of firms	% of total	Nr of centres	% of total
1	Computer Hardware	25	14,62	327	10,07
2	Electronic Equipment	19	11,11	336	10,35
3	Telecommunications Equipment	18	10,53	356	10,96
4	Automobiles & Parts	16	9,36	425	13,09
5	Leisure Goods	15	8,77	266	8,19
6	Aerospace & Defence	14	8,19	418	12,87
7	Electrical Components & Equipment	9	5,26	232	7,15
8	Consumer Electronics	8	4,68	59	1,82
9	Diversified Industrials	5	2,92	61	1,88
10	Electronic Office Equipment	5	2,92	70	2,16
11	Semiconductors	5	2,92	73	2,25
12	Computer Services	4	2,34	109	3,36
13	General Industrials	4	2,34	172	5,3
14	Health Care Equipment & Services	4	2,34	57	1,76
15	Household Goods & Construction	4	2,34	109	3,36
16	Durable Household Products	3	1,75	23	0,71
17	Pharmaceuticals	3	1,75	66	2,03
18	Technology Hardware & Equipment	3	1,75	10	0,31
19	Software	2	1,17	31	0,95
20	Construction & Materials	1	0,58	8	0,25
21	Industrial Machinery	1	0,58	15	0,46
22	Media	1	0,58	10	0,31
23	Medical Equipment	1	0,58	11	0,34
24	Support Services	1	0,58	3	0,09
		171	**100**	**3247**	**100**

Source: Own calculations based on JRC-IPTS R&D Internationalization Database, 2011

Table 2. Descriptive statistics

Number of R&D centre	3247
Companies in the R&D network	171
Countries in the R&D network	54
Cities in the R&D network	1345

Source: Own calculations based on the JRC-IPTS R&D Internationalization Database, 2011

3. Characteristics of the network of cities hosting ICT R&D

Table 3 summarises the main measures of the city network. Regarding the general connectivity of the network, the value of the network density parameter is 0,001. This clearly indicates that the network is not regular and far from being complete. This let us conclude that most of the cities included in our sample do not have R&D connections with all the remaining cities, but rather select, or are selected as, an R&D location. In comparison, international trade networks report the value of density between 0,38 (De Benedictis and Tajoli 2011) and 0,6 (Fagiolo, Reyes et al. 2007). Similarly, the density both of the global network of international R&D centres and of the global network of international technological collaboration at the country level reaches the level of density of 0,24 and 0,06 respectively (De Prato and Nepelski 2011; De Prato and Nepelski 2012). It has to be however mentioned that this low level of connectedness is a result of the choice of unit to study. Whereas all the above mentioned analyses use data aggregated at a country level, we go much deeper and take under investigation cities, which considerable increases the level of granularity. Regarding the remaining network indices, the betweenness centrality measure and clustering coefficient show that the network is very dispersed, but with a high degree of clustering between nodes. In other words, the network does not have a dominant gate-keeper and cities form "cliques" or clusters of tightly connected sub-groups.

Table 3. Indices of the network of R&D locations

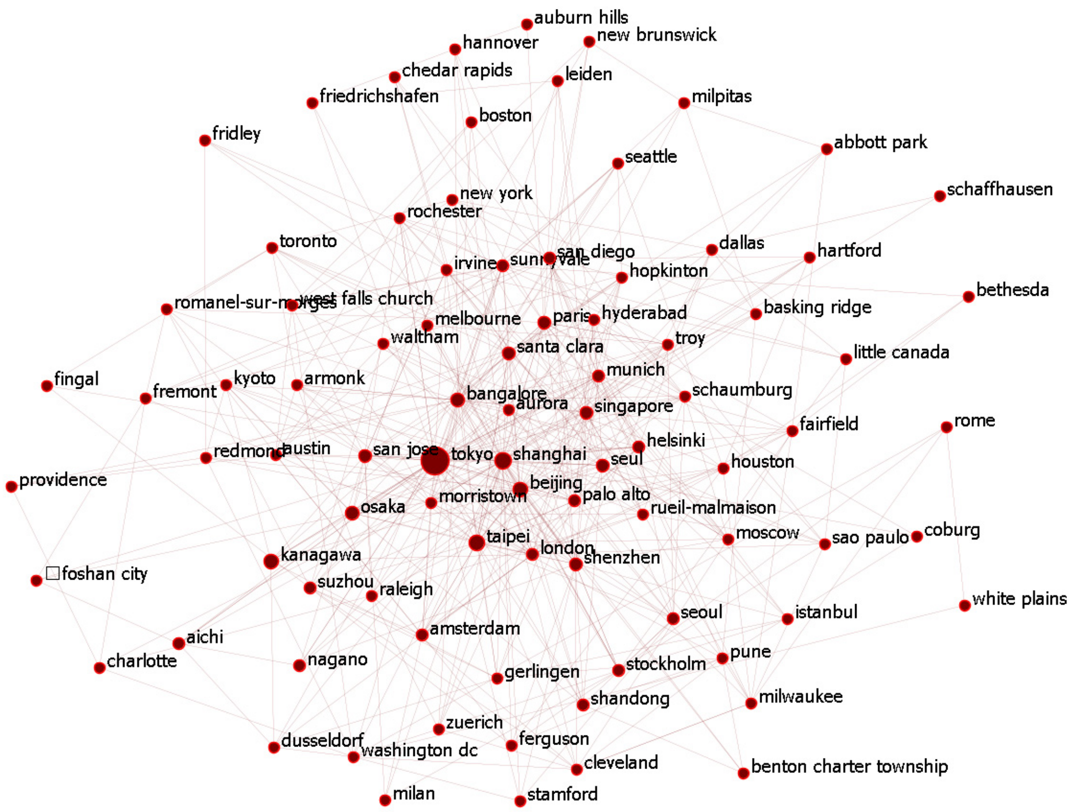
Number of cities	1345
Number of arcs	2478
Average degree	2,4
Density	0,001
Degree centrality	0,003
Closeness centrality	-*
Betweenness centrality	0,021
Clustering centrality	0,487

* cannot be computed due to a low level of network connectedness

Source: Own calculations based on JRC-IPTS R&D Internationalization Database, 2011

One powerful tool offered by the application of network analysis is the possibility to illustrate the relationships between the actors. Thus, our analysis of the network of cities hosting R&D centres continues with its graphical illustration in Figure 1. The arcs represent the existence of a relationship where a company from one city owns an R&D centres in another city. In order to make the graph more readable we limited the set of cities to those that have a level of centrality degree of at least 10, cities hosting and/or owning at least 10 R&D centres. As a direct result of the reduction of the network to cities with the total degree of 10, the graph representing only the selected nodes shows density of 0,071, as compared to 0,001 for the full sample. This indicates that cities belonging to the sub-network are better connected among each other, than cities with fewer R&D centres.

Figure 1. Reduced view of the network of R&D locations*



* Includes only cities hosting at least 10 R&D centres. Own calculations based on the JRC-IPTS R&D Internationalization Database, 2011.

A first look at Figure 1 reveals that, on the one hand, there are altogether 87 cities (down from 1345 for the full sample) that host at least 10 R&D centres. The nodes with the highest degree centrality include such cities as Tokyo, Shanghai, Taipei, Kanagawa and Beijing, showing a generally strong position of Asian cities and particularly some of the Chinese cities as a location of R&D centres. At the same time, however, the illustration shows the large number of Silicon Valley cities, which are smaller in size but large in numbers, occupying a significant number of positions in the network. This clearly suggests the necessity of finding a unit of comparison that would allow taking into account such discrepancies in size. Nevertheless, these observations show that, once a number of less meaningful cities in terms of the number of hosted R&D centres are excluded, there are only a few locations where high-tech R&D activity is concentrated and that these locations are very well connected between each other.

4. Connectivity, centrality and clustering of cities

Concerning the connectivity level of nodes, it is measures by in-degree, i.e. the number of R&D centres owned by firms from a city in other cities, and out-degree, i.e. the number of R&D centres hosted in a city which are owned by firms from other cities. The total connectivity is captured by the degree measures. The value of the degree parameter is relatively low, i.e. 2,4 (Table 3). Moreover, on average, the majority of the cities have few R&D centres. In other words, the connections between the cities are not very intensive in terms of the ownership and location of R&D centres.

Concerning betweenness centrality, which informs about the brokerage or "hub" role a node plays between groups, its low value additionally confirms of a core-periphery structure of the network (see Table 3). In other words, there are a few cities, forming the core of the network, that are connected with many other members of the network, and numerous cities that are connected only to the core cities. Again, the network of cities hosting R&D centres shows strong similarities to the network of international technological collaborations, in which, at least up to recently, no complex network structures have emerged (De Prato and Nepelski 2012).

An analysis of clustering coefficient, which reveals how much the partners of a node are themselves partners, i.e. how nodes cluster in groups, can be found, for example, in the studies of international trade (Fagiolo, Reyes et al. 2007). In the context of the network of cities hosting R&D centres, the value of clustering coefficient is 0,49, which is significantly higher than the value of network density (see Table 3). Thus, in contrast to a random graph where clustering coefficient is expected to be equal to network density, the network of network of cities hosting R&D centres is significantly more clustered than if the links were generated at random. Again, like in the case of international trade, it can be said that cities establish R&D relationships with cities that belong to the same group or cluster (Fagiolo, Reyes et al. 2007). This type of clustering behaviour lets us conclude that 'local' links tend to play an important role. It has to be however noted that local do not necessarily imply geographical proximity and that it can be rather interpreted as a pattern of interaction with the "usual suspects", who may represent either cities belonging to some regional group or just cities at a similar level of development.

5. Cities' positions in the network of R&D locations

Turning to the analysis of positions of cities in the network of cities hosting R&D centres, one of the most striking finding is that Tokyo appears at the top of each ranking presented in Table 4, confirming its strong position in the network as a source and destination of R&D services and, above all, as a hub of the network. Concerning the level of in-degree, i.e. the number of R&D centres owned by firms from a city in other cities, this ranking shows the ranking of cities in terms of corporate ownership and control of R&D centres located around the world. Here we can see that along with Tokyo, other Japanese and Korean cities are on the top of the ranking and that they are followed by such European and US cities. Interestingly, Shenzhen, one of Chinese cities, appears to be a meaningful receiver of R&D services from other cities and its level of in-degree places it ahead of such cities as Munich and Amsterdam.

Regarding the level of out-degree, reflecting the number of R&D centres located in a particular city, Tokyo holds the leading position along with other Japanese, Korean and US cities. Interestingly, however, the top 10 cities ranked by the number of R&D locations include two Chinese and one Indian city, confirming their attractiveness as a location of R&D activities by foreign companies. At the same time, no European city is among the top ten.

The betweenness centrality index in Table 4 shows a slightly different ranking of cities, which reflects the position of a city as a core or a hub in the network of international R&D centres and, hence, its strategic role in the network. Here again, Tokyo together with some other Japanese cities are among the top ten cities. However, the remaining of the ranking includes US, e.g. Sunnyvale, San Jose and Santa Clara, and European, e.g. London and Paris, cities.

Table 4. Cities' position in the network

	In-degree centrality		Out-degree centrality		Total degree centrality		Betweenness centrality	
Rank	City	Index value	City	Index value	City	Index value	City	Index value
1	Tokyo	226	Tokyo	107	Tokyo	258	Tokyo	0,185
2	Taipei	64	Shanghai	97	Shanghai	97	Taipei	0,081
3	Osaka	43	Kanagawa	69	Taipei	81	Sunnyvale	0,071
4	Seoul	40	Beijing	58	Kanagawa	73	London	0,068
5	Paris	24	Bangalore	50	Beijing	63	San Jose	0,067
6	Helsinki	23	Taipei	43	Osaka	53	Santa Clara	0,062
7	Shenzhen	23	Singapore	34	Bangalore	50	Paris	0,053
8	Santa Clara	22	San Diego	26	Seoul	40	Rochester	0,049
9	Palo Alto	19	San Jose	25	Shenzhen	39	Palo Alto	0,047
10	Stockholm	18	Seoul	24	San Jose	36	Shenzhen	0,045
11	Munich	16	Osaka	24	Santa Clara	34	Osaka	0,037
12	Amsterdam	15	Shenzhen	23	Singapore	34	Washington	0,036
13	Shandong	15	Aichi	22	Paris	34	Waltham	0,035
14	Foshan city	15	Suzhou	20	Aichi	27	Beijing	0,035
15	Fairfield	14	Santa Clara	16	Munich	27	Irvine	0,035
16	San jose	14	Sunnyvale	16	San Diego	26	Aurora	0,03
17	Schaumburg	14	Austin	15	Palo Alto	25	Fremont	0,03
18	Armonk	13	Moscow	13	Helsinki	24	Dusseldorf	0,022
19	Aurora	13	Munich	13	Seoul	24	Stamford	0,022
20	Gerlingen	13	Paris	13	London	23	Fairfield	0,021

Source: Own calculations based on the JRC-IPTS R&D Internationalization Database, 2011

The analysis of the cities ranked by different network indices shows that there are some structural differences in the characteristics between the cities of R&D network. In general, it can be said that there are three groups of cities. The first group includes cities in which the ownership and control of R&D centres spread around the world is concentrated. This group would include such cities as Tokyo, Taipei, Osaka, Seoul and Paris. The second group puts together cities that are the primary location of R&D activities. The most pronounced examples of this set include Tokyo, Shanghai, Kanagawa, Beijing, Bangalore and Silicon Valley cities. The last group is composed of cities that, due to their strategic position in the network, and not due to the number of R&D centres located or owned by companies based in them, can be considered as hubs of the network of R&D cities. This last group is dominated by the major R&D locations of Japan, Taiwan, the US and Europe. Looking at the composition of these cities, we can also expect that they play a role of 'regional hubs', which bring together the cities from the same region with remote cities.

6. Conclusions

The objective of the present paper was to create a map of R&D locations dispersed globally. The results of our research can be summarized as follows. First, we show that most of the cities do not have R&D connections with all the remaining cities, but rather select, or are selected as, an R&D location. This nexus of connections does not have a dominant gate-keeper and cities form "cliques" of tightly connected sub-groups. These sub-groups are linked through cities playing a role of intermediaries, i.e. hubs of the network. Thus, not only is the R&D activity concentrated in space, but also the nexus of connections between locations is limited. Second, there are structural differences in the characteristics between the locations. In general, it can be said that there are three groups of cities. The first group includes cities in which the ownership and control of R&D centres spread around the world is concentrated. To this group belong such cities as Tokyo, Taipei, Osaka, Seoul, Paris and the Silicon Valley cities. The second group consists of cities which mainly host R&D activities, e.g. Tokyo, Shanghai, Kanagawa, Beijing, Bangalore and Silicon Valley cities. The last group is composed of cities that, due to their strategic position in the network, and not necessarily due to the number of R&D centres located or owned by companies based in them, are hubs of the network. This last group includes Tokyo, Taipei and a number of Silicon Valley and European cities. These cities also play a role of 'regional hubs'. As a result, these locations are the main beneficiaries of spillovers between sub-groups and other externalities related to maintaining an intermediary role.

The results presented in this work have some important policy implications. Most importantly, as the emergence of the global innovation network is a result of the international division of innovation processes, policy makers should give a multinational dimension to innovation policies. In practical terms it means the following: First, although building a strong knowledge base is a necessary condition for participating in the global innovation network, it might not be a sufficient condition to generate the most out of this participation. Rather than designing policies driven by the notion of competition for innovation recourses and the corresponding payoffs, it might be advisable to create a mutually beneficial system of collaboration, taking into account interactions with a large number of players. Second, one of the major reasons behind the emergence of the global R&D network is the increasing complexity of technologies and business processes. This requires both firms and countries to specialize. Innovation policies should take this into account, instead of trying to follow some "best practice" examples. Third, innovation policies oriented towards forming and joining a network would include a strategy to identify and select partners with complementary assets. Lastly, taking into account mutual dependencies in the R&D process, collaboration between countries and regions is likely to depend on the development of a holistic IP regime that creates the *right* balance between countries that source and countries that produce R&D services.

In conclusion, despite some limitations, the paper provides a number of valuables insights concerning the structure of the R&D network. The results presented here show that the methodology applied to the issue of MNEs in geographic space is well justified and, once improved, promises delivering further insights into the topic at stake.

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