Proceedings of 2017 International Conference of Asian-Pacific Planning Societies

Pattern Discovery in U.S. Semiconductor Co-patenting Data

Der-Shiuan Lee[1] Szu-Ying Chen[2]

Abstract

Due to the development of international division of labor and advanced information and communication technologies, an alternative perspective stresses interregional collaborative networks in which individuals groups are embedded in wide-ranging webs of relationships. The existence of collaborative networks raises challenges for understanding the new geography of invention and innovation. The study explores the pattern of the network of geographical co-invention by comparing the co-patenting network in the year of 2009 and 2015. By focusing on the U.S. semiconductor devices patents and particularly their inventors and assignees' geographical locations, the study uses social network analysis to reveal the phenomena of creative knowledge flow and international collaboration. Moreover, the study uses spatial statistics approach to investigate nodal associations, network dependence, and the relationships between the networks and city's inventive competitiveness. The importance of the study is to clarify the pattern of co-invention in the semiconductor industry. The findings will enhance the co-inventive platform between cities and worldwide megacenters for the restructuring on major technology industries.

Keywords: Networks, Knowledge exchange, Co-invention, Co-patenting, Semiconductor device

[1] Assistant Professor, Chinese Culture University, Taipei, Taiwan

[2] Graduate Student, Chinese Culture University, Taipei, Taiwan

1. Introduction

Spatial concentration of economic actors, such as inventors, firms, and research institutions, in clusters enhances personal interaction and communication, labor mobility, and research collaboration (Bathelt, 2005; Ponds *et al.*, 2007). Clusters of invention and innovation, tied to localized knowledge spillovers in and among developed countries, regions, and cities, have been extensively documented (Jaffe, 1989; Acs *et al.*, 1994; Almeida and Kogut 1999; Audretsch and Feldman, 1996; Anselin *et al.*, 1997; Fischer, 2003). Recently, new information and communication technologies reduce costs of moving knowledge and enhance access to distant partners (Salazar *et al.*, 2003). Knowledge flows are possible to circulate through wide ranging global connections (Rondé and Hussler, 2005; Maggioni et al., 2007; Knoben, 2009). Social relationships are vital in this kind of network-based relationship that links economic actors in different countries and cities. Advanced technologies such as semiconductor where research collaboration has gradually become essential for research collaborations and co-inventive productivities (Ponds *et al.*, 2007; Gertler and Levitte, 2005). The existence of collaborative networks raises critical challenges for understanding the new geography of invention and innovation.

This paper explores the structural properties of the network-based co-invention in the U.S. semiconductor patents. A central goal is to figure out the nature and strength of co-inventive relationships among countries and cities. The existence of co-invention networks raises critical challenges for understanding the new geography of invention and innovation. I focus on co-invention networks of semiconductor patenting because technological advance in this field involves the deepening of collaboration and the broadening of inventor relationships. Networks are constructed by tracking inventors who participate in the U.S. semiconductor co-patenting in 2009 and 2015. I attribute each co-patent to the corresponding metro areas where the inventors reside. Investigating specific structural properties of the networks helps answer the following interrelated questions. Are closely connected groups of areas evident in the system, are some groups more critical than others, are the groups international, national, or regional, and are the groups stable over time? What are the pivotal metro areas, are centrality rankings stable? Finally, as collaboration grows, has enhanced complexity allowed knowledge flows to follow more routes?

2. Knowledge exchange and network-based space

Economic geographers have long recognized that knowledge is a key to contribute economic growth and regional development. Nelson and Winter (1982) initiated economic interest in how tacit knowledge exchange shapes technological advance. Maskell and Malmberg (1999) argued that tacit knowledge including intuition, know-how, and personal skills is a prime determinant of the geography of invention and innovation. Interpersonal knowledge flows that are restricted in space influence local inventive activities through interactive learning and sharing (Gertler and Levitte, 2005). Geographical proximity makes such interaction easier and speeds up the flows of creative ideas. Gertler (2007) mentioned three related elements to this argument, First, tacit knowledge is difficult to exchange over long distances, which makes it spatially sticky. Second, economic actors exchange tacit knowledge only if they share common social contexts, which are locally defined. Third, the dynamic nature of innovation requires the process of 'learning through interacting. These three elements above lead to the development of localized knowledge spillovers (herafter LKSs), which constitute knowledge externalities bounded in space (Audretsch, 2001; Howells, 2002; Gertler, 2007). Considerable research effort has been made to identify the nature and strength of LKSs. Jaffe's (1989) empirical work found that industrial patenting (an indicator of innovative output) responds positively to knowledge spillovers from university research (an indicator of innovative input) conducted in the same US state. Building upon Jaffe's work, Acs *et al.* (1994) and Audretsch and Feldman (1996) found significant evidence in favor of the agglomeration advantages by using innovation counts instead of patent data. Approaches that are more direct have tracked the geography of patent citations (Jaffe et al., 1993; Almeida and Kogut,

1999). Estimating regional knowledge production functions permits incorporation of spatial effects in the form of spatial autocorrelation to understand the distinctive roles of industrial and university research on invention and innovation (Anselin *et al.*, 1997; Varga, 2000; Autant-Bernard, 2001). The empirical studies have found that knowledge flows are localized by showing that higher rates of research and development, invention and innovation, entrepreneurial activity, and high-technology production are bounded in space (Feldman, 1999).

Other empirical studies stress an increasing necessity for access to external knowledge to trigger successful innovation and regional technological development. Breschi and Malerba (2001) argued that strong external links with other regions are vital competitive advantages. Bathelt et al. (2001) showed that dynamic firms in successful clusters build and maintain a variety of internal and external knowledge resources. In addition, advanced information and communication technologies (herafter ICTs) reduce costs of moving knowledge and increase access and availability of universal resources (Torre and Rallet, 2005). Understanding the role of knowledge in driving regional economic growth is shifting from a focus on closed territorial relationships, towards an emphasis on extra-local links with distant markets and technological resources (Coe and Bunnell 2003; Yeung, 2005; Vallance, 2007). The concepts of extra-local links and external knowledge resources provide new ways for explaining the dynamics of invention and innovation. Recent technological and commercial successes of many firms, for example, many ties between firms in Silicon Valley and Taiwan are shaped by interpersonal connections between Taiwanese nationals with educational and working experience in both places (Saxenian and Hsu, 2001). Amin and Cohendet (2005) argued that a network-based system is a disconnected spatial ecology of knowledge that can be held in place as relational knowledge. It is composed of relational ties between economic actors from different places allowing for the possibility of seeing a broad range of knowledge flows with a twofold advantage. First, it holds knowledge to be place-specific for different markets where inventive activities are specifically aligned with the distinctive needs of local clients and customers (Vallance, 2007). Second, it translates varied ideas and practices into a corporate template where interactive learning takes place among actors through collaborative or other joint activities (Allen, 2000). Overall, Cooke (2006) argued that some high-technology research centers serve as magnets for profit-seeking biotechnology firms because these research centers operate with relatively open science conventions. Such 'openness' in innovation may have certain 'club' characteristics in a network-based system where member cities enjoy knowledge diffusion and exchange with one another at a global scale.

Network-based approaches provide excellent analytical tools to assess knowledge flows in space. The rise of collaborative networks, as Amin and Cohendet (2005) explained, 'is precisely what has made trust, intimacy, and familiarity possible at a distance and thereby allows learning to take place' (p. 470). Interactive learning and deliberate collaboration with non-local partners are crucial for invention and innovation success (McKelvey *et al.*, 2003; Gertler and Levitte, 2005; Birch, 2007). A conceptual network of interregional co-invention is presented with an emphasis on the U.S. semiconductor co-patenting data for the following reasons. First, intense co-patenting activities are particularly significant in the field of U.S. semiconductor industry as a large portion of value-chains (e.g., venture capital, basic research, R&D, human resources) occurs in few global cities (Cooke, 2006). Coenen *et al.* (2004) mentioned that knowledge circulation in such places originates in centers of excellence -- leading universities and large companies. Moreover, these megacenters integrate different semiconductor clusters forming competitive niches among dense local actors and stretches knowledge domains through networks over space (Coenen *et al.*, 2004; Cooke, 2006). Second, the global circulation of knowledge through extra-local links provides a diversity of knowledge exchange opportunities for local learning and invention. This scene is viewed as individual cities linked to and integrated with a global network-based system. Each city has a distinctive knowledge architecture that supports local clients and customers, but they also provide markets and economies of scale for firms whose activities span multiple distant locations (Amin and Cohendet, 2005; Gertler and Levitte, 2005). Access to the systems is of particular importance for inventive semiconductor firms located in remote areas where research capacity and resources are insufficient. Since successful networking strategies assist in accessing external

knowledge, remote firms crucially rely on global networks (Simmie, 2003; Fontes, 2005). Finally, network patterns of the U.S. semiconductor co-invention are encapsulated in co-patent data, which occur when a patent generated by two or more inventors (Cantner and Graf, 2006; Ejermo and Karlsson, 2006). Ó hUallacháin and Lee (2014) emphasized the significance of co-paten tallies as an indicator to investigate interregional knowledge flows

3. Conceptual framework

Knowledge flows circulate in space in various forms and through different channels. Cassi and Morrison (2007) presented a four-way classification of channels of knowledge transmission, which are modified and shown in Figure 1. The channels of knowledge transmission through social networks are classified into two dimensions: direction of knowledge flows and relationship between inventors. The former refers to the flows of knowledge, either in one-way or two-way directions, while the latter refers to the relationship between inventors, either through formal or informal agreements. The channels in the four quadrants differ according to the influence of social networks on knowledge flows. The upper left quadrant shows unilateral knowledge flows that are transmitted through formal relationships. The interactions typically occur in inter-organizational networks such as licensing and consulting agreements whose one-way ties occur between firms. In social network analysis, the directions of these flows are important. The lower left quadrant is characterized by formal inter-organizational relationships and bilateral knowledge flows. Examples include co-patenting, R&D alliances, and cross-firm task forces. These corporate relationships emphasize the importance of knowledge collaboration and exchange through reciprocal agreements or other official relationships. There is no differentiation in the direction of knowledge flows. The upper right quadrant occurs at the individual worker level. Job mobility is the most common example of this type of knowledge transmission. Since knowledge embodied in human capital is tacit, the mobility of skilled workers forges knowledge flows between firms (Cassi and Morrison, 2007). The lower right quadrant captures informal social networks of individuals, but with an emphasis on interpersonal communication. For example, people from different communities interact by sharing experience and expertise. Common understanding and mutual trust are essential in these exchanges. This paper focuses on co-inventive activity over time and space with an emphasis on bilateral knowledge flows in formal co-patenting relationships of inventors (as shown in the lower left quadrant of Figure 1).

		Relationship between inventors	
		Formal	Informal
Direction of knowledge flows	Unilateral	Licensing/ Consulting	Job mobility
	Bilateral	Co-patenting/ R&D alliance	Interpersonal know-how exchange

Fig. 1. Cross-classification of channels of knowledge exchange

I apply social network concepts and methods to figure out interregional co-patenting system. Polanyi (1996) argued that knowledge exchange is embedded in individuals who reside in a city Figure 2 shows the conceptual framework of interregional co-invention. By linking an interregional network and its corresponding personal social network, the upper part of the figure refers to a simple geographical space with metro areas A to F. The lower part is its personal social network counterpart, as individual inventors are located in different metro areas. Links in the lower part are co-inventive activities between inventors. Some inventors have extra-local relationships with inventors located in other areas, while others only collaborate with local partners. Social relations underpin and facilitate the interaction and communication that lead to

co-patenting. These inventor-ties shape the interregional network shown in the upper part of Figure 2. Metro area C, for example, is directly connected to A, D, and E, indirectly connected to B, and has no connection with F. Inventors in metro area F only co-invent with local partners, but not exchange knowledge with outside inventors. They are isolated from direct bonds with non-local inventors. In this conceptual network-based system, metro area A and B are the mostly tied because two of A's inventors co-invent with an inventor in B. No other pair of metro areas has more than one direct link with a particular co-inventor in another area.

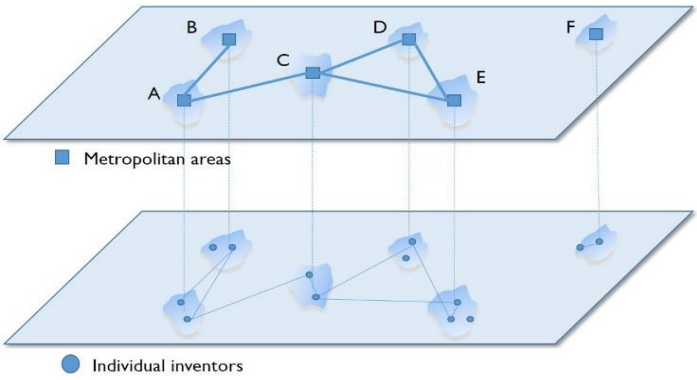

Fig. 2. Network of geographical co-invention and knowledge exchange

4. Methodology

This analysis of the interregional network of co-invention mainly investigates the U.S. semiconductor co-patenting ties formed by inventors and ascribes their connections to metro areas where they reside. While I assume that metro areas share knowledge through co-patenting and that each metro has a competitive niche that is integral to the network, the paths I sketch are rudimentary proxies or mere glimpses into knowledge exchange that occurs in collaborative encounters. Detailed descriptions of the methods used below are available in Wasserman and Faust (1994), Scott (2000), Knoke and Yang (2008).

4.1. Network components and cohesive subgroups

The first task is to identify the network components and cohesive sub-groups of interregional co-invention in the year of 2009 and 2015. A component is a connected set of nodes (i.e., metro areas) with either direct or indirect links to each other. A cohesive sub-group is a subset of a component with relatively strong or frequent ties (Wasserman and Faust, 1994). Two traits identify cohesive sub-groups. The number of neighbors of each node is entitled the k-cores, while the frequency of connection between each nodal pair is entitled the m-slices procedure (Scott, 2000; Knoke and Yang, 2008). Identification of cohesive sub-groups permits addressing several interrelated questions. Is the core of the network structured into sub-groups focused on certain pivotal centers? Do members of sub-groups have distinctive geographical settings? Do metro areas vary in connection intensity and are these connections stable over time?

4.2. Network centrality

The second task is to assess the extent to which a global-level network has a centralized structure. Scott (2000), Knoke and Yang (2008) presented a measure with three properties (degree, closeness, and betweenness) that I use to reveal the centrality of a whole co-invention network by emphasizing some interrelated questions: How tightly organized is the network around its most central area(s)? Is the level of centrality stable over time? Network centrality is generated by calculating the variability of all individual metro nodes' centralities around the one with the largest

centrality.

Network degree assesses the extent to which an entire co-invention network has a centralized structure. Scores range from zero and unity. A zero occurs in a regular graph where each node has the same degree. The maximum value of unity occurs in a star graph as all metro areas tie to one center. In comparing interregional co-invention networks over time, a wide range of network degree most likely occurs. **Network closeness** examines assesses the variability of all metro nodes' closeness centralities around the largest closeness centrality. The minimum value of zero occurs in a regular graph, while the maximum value of unity occurs in a star graph. Large values occur when a few metro areas are highly central, and the rest occupy less pivotal positions. In contrast, if the measure has a relatively low value, metro areas are generally connected with other with similar central positions in the network. **Network betweenness** is the variability of all nodal betweenness scores around the largest nodal betweenness score. The maximum value of unity when a single dominant metro node sits on all geodesic paths in a star graph. The minimum value of zero occurs when every metro node has the same betweenness score. The closer a network betweenness approaches one, the more unequally distributed is betweenness-based centralized in a network.

4.3. Nodal centrality

The third task is to examine the local-level network properties of geographical co-invention by identifying the pivotal metro areas. Specific questions addressed include the following: How important is an urban area in transferring knowledge to other areas? To what extent does an urban area control or mediate knowledge exchange in the network? Are centrality-based rankings of areas stable?

Nodal degree tallies the number of direct ties an individual area has with all others. Scores range from zero to unity. A zero value occurs if node i has no connection with another node. If node i is directly tied to all g-1 other nodes, the maximum value is unity. This measure is straightforward in measuring and comparing nodal centrality. The network center is simply the metropolitan area with the most direct connections. **Nodal closeness** assesses knowledge exchange through both direct and indirectly connections. It is an inverse function of the geodesic distances from a given node to all others. A metro area with a high nodal closeness is critical in facilitating knowledge across the network. Nodal closeness requires a focus on the main component with the exclusion of isolates and subcomponents. **Nodal betweenness** calculates the extent to which a metro area is located on geodesic paths connecting other metro areas. A geodesic path between two metros is the shortest and most efficient channel for transferring knowledge. If more than one geodesic path links two areas, paths with the same number of segments are equally likely to be selected. Relatively large values identify gatekeepers of information exchange.

5. Data and observations

Aspects of knowledge collaboration and exchange are encapsulated in co-inventive activities, which occur when a patent collaborated by two or more inventors. I follow Hall *et al.* (2001), Cortright and Mayer (2002), Hevesi and Bleiwas (2005), and Ó hUallacháin and Lee (2014) in using U.S. patent classes 257, 326, 438, and 505 to define semiconductor devices. Class 527 are active solid-state devices (e.g., transistors, solid-state diodes); Class 326 is electronic digital logic circuitry; Class 438 is semiconductor device manufacturing: process; Class 505 encompasses superconductor technology including apparatus, material, and process. The Patents in the year of 2009 and 2015 were provided by the U.S. Patent and Trademark Office (USPTO, 2017). The geographical observations are metro areas in developed countries where inventors of U.S. semiconductor devices reside, while my previous paper only focused on U.S. metropolitan areas, foreign investors were ignored and restricted the analysis to domestic aspects of the American urban system (Lee, 2016). The U.S. Office of Management and Budget (herafter OMB) defined 382 Metropolitan Statistical Areas in 2015 (OMB, 2017), while other countries' metro areas were

measured by the Organization for Economic Co-operation and Development (herafter OECD) metropolitan areas database published in 2012 (OECD, 2016). Owing to the uneven distribution of co-patents across countries, metro areas without any co-patented awards are discarded. This sidesteps swamping the analysis with cases that have no co-patenting and the likelihood that they would be mistakenly identified as outliers. The number of geographical observations is reduced to a few larger metro areas that had at least one semiconductor co-patent awarded in 2009.

A co-patent is defined as a patent invented by two or more inventors that is distinguished from other sole patents whose inventors are individuals. I specify the geographical co-invention in the U.S. patents of semiconductor devices by attributing each co-patent to the corresponding metro area(s) where their inventors reside. Co-patents with inventors living in multiple areas are allocated fractionally, which corresponds with Maggioni *et al.* (2007) and Ejermo and Karlsson (2006). For example, if a co-patent has four inventors located in four different metro areas, one-quarter of the co-patent is allotted to each area. The website of U.S. Bureau of Economic Analysis (herafter BEA) provided the job data (BEA, 2016).

5.1. Description of semiconductor devices patents

Table 1 shows the number of U.S. semiconductor devices patents that is gradually larger and growing—from 6,306 in 2009 to 7,567 in 2015. Co-patenting increased faster—from 75.88% (4,785 out of 6,306) to 78.21% (5,918 out of 7,567). Figure 3 depicts the percentage of U.S. sole semiconductor patents by country in 2009 and 2015. Japan accounts for up to 32.12% in 2009 and 34.02% in 2015 of single inventor in semiconductor devices. U.S., South Korea, Taiwan also function as intensive centers of semiconductor invention with 27.11%~28.03%, 15.16%~18.34%, and 8.16%~9.34% of sole patent shares, respectively, followed by Germany (4%~5.02%) and China (3.6%~3.76%).

Figure 4 shows the team size for co-patenting varies widely. The number of inventors per co-patent is up to 16 inventors in 2015 and the majority of co-patenting types are 2 and 3 inventors per patent. Average team size increased from 3.25 inventors in 2009 to 3.75 inventors in 2015.

Table 1. Number of U.S. semiconductor patents, 2015 and 2009

Type of patent	2015	Type of patent	2009
Sole patents	1,649	Sole patents	1,521
Co-patents	5,918	Co-patents	4,785
Total	7,567	Total	6,306
% of co-patents	78.21%	% of co-patents	75.88

Source: The USPTO patent database (USPTO, 2016)

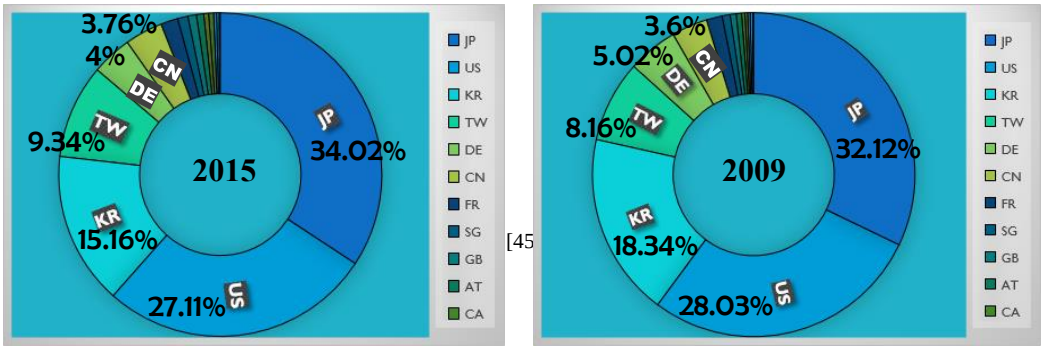

Fig. 3. Percentage of U.S. sole semiconductor patents by country, 2015 and 2009

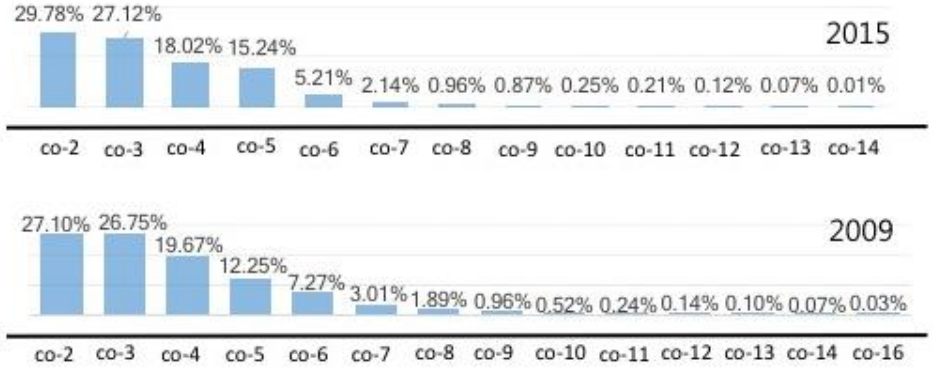

Fig. 4. Percentage of team size of U.S. semiconductor co-patents, 2009 and 2015

6. Results

6.1. Geographical pattern of U.S. semiconductor co-patenting

Table 2 shows the geographical distribution of U.S. semiconductor co-patenting in 2009 and 2015at the national level. While the semiconductor collaborations are dominated within the same country (over 90% of co-patenting, referred to as intra-national knowledge flows), the overall pattern reveals increasing non-domestic collaborations, from 17% in 1979 to 38% in 2009. Moreover, a growing number of countries jointly participated in co-patenting, leading to a wider network of geographical co-invention. In 2009, international co-patenting never exceeded four countries, while by 2015, the maximum co-patenting breadth extended to five countries. This is widening geographical span of co-invention confirms that semiconductor advance is deepening and broadening across the geographical boundary.

Table 2. Geographical distribution of U.S. semiconductor co-invention, percentage of domestic and international co-patenting, 2015 and 2009

Types of co-patenting	2015		2009	
	Inventors	%	Inventors	%
Intra-national (domestic) knowledge flows	20,363	91.73	17,121	94.04
International knowledge flows	1,836	8.27	1,085	5.96
Co-patenting across 2 countries	1,665	7.50	987	5.42
Co-patenting across 3 countries	148	0.67	86	0.47
Co-patenting across 4 countries	18	0.08	12	0.07
Co-patenting across 5 countries	5	0.02	--	--

Source: USPTO, 2017

6.2. Countries and metro areas participating in U.S. semiconductor devices co-patents

Table 3 depicts the characteristics of U.S. semiconductor co-patents at the national and metropolitan levels in 2015. The 2-inventor co-patents mostly occur with inventors located in developed countries, particularly U.S. (35.56%), Japan (28.36%), South Korea (11.1%), Taiwan (9.67), Germany (4.54%), and China (2.92%). However, these high co-inventive countries have different characteristics of urban systems. For example, In U.S., 81.39% of inventors come from several metro areas including San Jose-San Francisco, New York, Boise, Albany, Phoenix, Los Angeles, Boston, Dallas, San Diego, Raleigh, Austin, and Burlington. Japan only has three metro areas (Tokyo, Osaka, and Nagoya) that contribute 83.75% of inventors, while over 85% of inventors locate in Seoul, South Korea. Nearly half of Taiwanese inventors occur in the city of Hsinchu, where knowledge flows between public and private sectors are intensive concentrated

in the Hsinchu Science Park. Germany's largest semiconductor co-patenting cities are Munich and Dresden, followed by Regensburg and Stuttgart, while Shanghai, Beijing, and Guangzhou are the top China's biggest cites for the semiconductor collaboration. A similar pattern has been found in the 6-inventor co-patents, as shown in the lower part of Table 3. Taiwanese replaces Korean as the third place in the semiconductor co-patenting.

Table 3. Characteristics of U.S. semiconductor co-patents at the national and metropolitan levels, 2015

2-inventor co-patents

1. US (548 out of 1,541)

san jose	300	27.37%
new york	123	11.22%
boise	84	7.66%
albany	65	5.93%
phoenix	62	5.66%
los angeles	57	5.20%
boston	54	4.93%
dallas	45	4.11%
san diego	29	2.65%
raleigh	26	2.37%
austin	25	2.28%
burlington	22	2.01%
		81.39%

2. Japan (437 out of 1,541)

tokyo	534	61.10%
osaka	133	15.22%
nagoya	65	7.44%
		83.75%

3. Korea (171 out of 1,541)

seoul	292	85.38%

4. Taiwan (149 out of 1,541)

hsinchu	144	48.32%
northern tw	90	30.20%
southern tw	36	12.08%
		90.60%

5. Germany (70 out of 1,541)

munich	39	27.86%
dresden	39	27.86%
regensburg	28	20.00%
stuttgart	10	7.14%
		82.86%

6. China (45 out of 1,541)

shanghai	38	42.22%
beijing	30	33.33%
guangzhou	22	24.44%
		100.00%

6-inventor co-patents

1. US (1,524 out of 4,348)

san jose	381	25.00%
new york	347	22.77%
albany	181	11.88%
portland	68	4.46%
phoenix	52	3.41%
burlington	50	3.28%
boise	42	2.76%
san diego	41	2.69%
los angeles	37	2.43%
dallas	30	1.97%
austin	30	1.97%
TOTAL	1259	82.61%

2. Japan (928 out of 4,348)

tokyo	590	63.58%
osaka	114	12.28%
nagoya	59	6.36%
TOTAL	763	82.22%

3. Taiwan (728 out of 4,348)

hsinchu	364	50.00%
northern tw	168	23.08%
southern tw	117	16.07%
TOTAL	649	89.15%

4. Korea (632 out of 4,348)

seoul	562	88.92%

5. Germany (160 out of 4,348)

dresden	43	26.88%
regensburg	35	21.88%
munich	23	14.38%
stuttgart	14	8.75%
ruhr	11	6.88%
frankfurt	8	5.00%
TOTAL	134	83.75%

6. China (96 out of 4,348)

beijing	44	45.83%
shanghai	36	37.50%
TOTAL	80	83.33%

6.3. Most inventive countries and metro areas participating in U.S. semiconductor co-patents

I specify the geography of semiconductor co-patenting by attributing each co-patent to the countries and metro areas where the inventors reside. Co-patents with inventors living in multiple metro areas are allocated fractionally. Table 4 (left side) lists the world's most inventive countries and metro areas participating in 2015 U.S. semiconductor devices co-patents. Besides U.S., inventive countries on the list are concentrated in northern Europe (e.g., Germany, France, U.K., Austria, Italy, and Belgium) and Asia (e.g., Japan, South Korea, Taiwan, China, Singapore, and Malaysia). At the metropolitan level, the top 10 inventive metro areas in order of most inventive

are Tokyo (13.94% shared co-patents), Seoul (11.49%), San Jose-San Francisco (9.9%), Hsinchu (6.85%), New York (5.68%), Osaka (3.49%), the northern Taiwan city-region (3.24%), Albany (2.65%), the southern Taiwan city-region (2.23%), and Phoenix (1.68%).

Table 4. The world's most inventive countries and metro areas participating in U.S. semiconductor co-patents, 2015

Country	shared co-patents	%
1. United States	2454.95	32.45%
2. Japan	1929.74	25.50%
3. Korea	1046.20	13.83%
4. Taiwan	970.20	12.82%
5. Germany	342.57	4.53%
6. China	229.98	3.04%
7. France	120.85	1.60%
8. Singapore	110.03	1.45%
9. United Kingdom	53.87	0.71%
10. Austria	41.22	0.54%
11. Italy	37.94	0.50%
12. Belgium	32.91	0.43%
13. Canada	32.12	0.42%
14. Malaysia	30.29	0.40%
15. Israel	26.87	0.36%
16. Netherlands	24.35	0.32%
17. Switzerland	17.08	0.23%
18. India	11.15	0.15%
19. Sweden	8.86	0.12%
20. Finland	8.79	0.12%

MSA	Country	shared co-patents	%
1. Tokyo	JP	824.88	13.94%
2. Seoul	KR	679.82	11.49%
3. San Jose	US	586.14	9.90%
4. Hsinchu	TW	405.27	6.85%
5. New York	US	336.06	5.68%
6. Osaka	JP	206.54	3.49%
7. Northern TW	TW	191.7	3.24%
8. Albany	US	156.97	2.65%
9. Southern TW	TW	132.18	2.23%
10. Phoenix	US	99.29	1.68%
11. Nagoya	JP	96.88	1.64%
12. Singapore	SG	93.03	1.57%
13. Boise	US	83.78	1.42%
14. Central TW	TW	82.3	1.39%
15. Los Angeles	US	77.51	1.31%
16. Burlington	US	74.51	1.26%
17. Boston	US	70.78	1.20%
18. Beijing	CN	69.83	1.18%
19. Dresden	DE	67.13	1.13%
20. Grenoble	FR	64.34	1.09%

7. Conclusions and future work

This article provides insights into the collaborative pattern in U.S. semiconductor devices patents. I track co-patenting ties in interregional networks to account for bilateral knowledge exchange in the world wide large metro areas. Results show that U.S. semiconductor devices presents wider geographical structures of collaboration over time as a growing number of countries participated in co-patenting activities. Interregional co-inventions are still dominated by domestic inventors compared with inventors collaborating with other countries, indicating that domestic knowledge flows remained robust. At the national level, Japan, South Korea, Taiwan, and Germany are major foreign countries in U.S. semiconductor devices patenting, while at the metro level, Tokyo, Seoul, San Jose-San Francisco, Hsinchu, and New York are mega-centers on co-invention. Moreover, most foreign countries' co-patenting activities concentrate on a few metro areas, while Taiwan has great performance across the west part of island, including northern, central, southern regions, and Hsinchu.

Future work will organize the 2009 U.S. semiconductor devices patent and construct the interregional networks of co-invention for the year of 2009 and 2015. I particularly will focus on the role of metro areas in three distinct aspects: components and cohesive subgroups, centralization and centrality, and positions and relational clusters. The characteristics of network components reveal whether some metro areas are able to collaborate with one another by means of relatively strong ties. The centers of a network identify metropolitan areas with the best access to knowledge flows. The patterns of network positions group metro areas into relational clusters.

These empirical analyses are better understanding the network properties and the diverse roles of metropolitan areas in systems of knowledge exchange.

8. References

1. Acs, Z. J., Audretsch, D. B., and Feldman, M. P. (1994). R&D spillovers and recipient firm size, *Review of Economic and Statistics*, 76(2): 336-367.
2. Agrawal, A., Cockburn, I., and McHale, J. (2006). Gone but not forgotten: Knowledge flows, labor mobility, and enduring social relationships, *Journal of Economic Geography*, 6: 571-591.
3. Allen, J. (2000). Power/economic knowledge: symbolic and spatial formations. In: Bryson, J., Daniels, P.W., Henry, N., Pollard, J. editors. Knowledge, Space, Economy. London: Routledge; p. 15-33.
4. Almeida, P. and Kogut, B. (1999). Localization of knowledge and the mobility of engineers in regional networks, *Management Science*, 45(7): 905-917.
5. Amin, A. and Cohendet, P. (2005). Geographies of knowledge formation in firms, *Industry and Innovation*, 12(4): 465-486.
6. Anselin, L., Varga, A., and Acs, Z. J. (1997). Local geographic spillovers between university research and high technology innovations, *Journal of Urban Economics*, 42: 422-448.
7. Audretsch, D. B. (2001). The role of small firms in U.S. biotechnology clusters, *Small Business Economics*, 17:3-15.
8. Audretsch, D. B. and Feldman, M. P. (1996). R&D spillovers and the geography of innovation and production, *America Economic Review*, 86(3): 630-652.
9. Autant-Bernard, C. (2001). Science and knowledge flows: evidence from the French case, *Research Policy*, 30: 1069-1078.
10. Bathelt, H. (2005). Geographies of production: growth regimes in spatial perspective (II) -- knowledge creation and growth in cluster, *Progress in Human Geography*, 29(2): 204-216.
11. Bathelt, H., Malmberg, A., and Maskell, P. (2004). Clusters and knowledge: Local buzz, global pipelines and the process of knowledge creation, *Progress in Human Geography*, 28(1): 31-56.
12. Birch, K. (2007). Knowledge space and biotechnology, *Geography Compass*, 1(5): 1097-1117.
13. Breschi, S. and Lissoni, F. (2003). Mobility and social networks: Localized knowledge spillovers revisited, *CESPRI working paper*, *142*, Universitá Bocconi, Milano.
14. Breschi, S. and Malerba, F. (2001). The geography of innovation and economic clustering: Some introductory notes, *Industrial and Corporate Change*, 10(4): 817-833.
15. Cassi, L. and Morrison, A. (2007). Social networks and innovation: Concepts, tools, and recent empirical contribution. ISCTE, Lisbon, Portugal, p.6.
16. Coe, N. M. and Bunnell, T. G. (2003). 'Spatializing' knowledge communities: towards a conceptualization of transnational innovation networks, *Global Networks*, 3(4): 437-456.
17. Coenen, L., Moodysson, J., and Asheim, B. T. (2004). Nodes, networks and proximities: On the knowledge dynamics of the Medicon Valley biotech cluster, *European Planning Studies*, 12(7): 1003-1016.
18. Cooke, P. (2006). Global bioregional networks: a new economic geography of bioscientific knowledge, *European Planning Studies*, 14 (9): 1265-1285.
19. Cortright, J. and Mayer, H. (2002). *Signs of life: The growth of biotechnology centers in the U.S*. The Brookings Institution, Washington, DC. U.S.
20. Ejermo, O. and Karlsson, C. (2006). Interregional inventor networks as studies by patent coinventorships, *Research Policy*, 35: 412-430.
21. Feldman, M. P. (1999). The new economics of innovation, spillovers and agglomeration: A review of empirical studies, *Economics of Innovation and New Technology*, 8(1): 5-25.
22. Fischer, M. M. and Varga, A. (2003). Spatial knowledge spillovers and university research: Evidence from Austria, *The Annals of Regional Sciences*, 37: 303-332.

23. Fontes, M. (2005). Distant networking: The knowledge acquisition strategies of 'out-cluster' biotechnology firms, *European Planning Studies*, 13(6): 899-920.
24. Gertler, M. S. (2007) Tacit knowledge in production system: how important is geography? In: Polenske, K. R. editor. *The Economic Geography of Innovation*. New York, NY: Cambridge University Press; 2007. p. 87-111.
25. Gertler, M. S. and Levitte, Y. M. (2005). Local nodes in global networks: The geography of knowledge flows in biotechnology innovation, *Industry and Innovation*, 12(4): 487-507.
26. Hall, B. H., Jaffe, A. B., and Trajtenberg, M. (2001). *The NBER patent citation data file: Lessons insights and methodological tools.* Working Paper 8498, U.S. National Bureau Economic Research.
27. Hevesi, A. G. and Bleiwas, K. B. (2005). *The economic impact of the biotechnology and pharmaceutical industrial*. Report 11-2005, Office of the State Comptroller, New York, U.S.
28. Howells, J. R. L. (2002). Tacit knowledge, innovation and economic geography, *Urban Studies*, 39(5-6): 871-884.
29. Jaffe, A. B. (1989). Real effects of academic research, *American Economic Review*, 79(5): 957-979.
30. Jaffe, A. B., Trajtenberg, M., and Henderson, R. (1993). Geographic localization of knowledge spillovers as evidenced by patent citations, *Quarterly Journal of Economics*, 108: 577-598.
31. Knoben, J. (2009). Localized inter-organizational linkages, agglomeration effects, and the innovative performance of firms, *The Annals of Regional Science*, 43: 757-8-79.
32. Knoke, D. and Yang, S. (2008). *Social Network Analysis*. London, U.K.: Sage Publications.
33. Lee, D. S. (2016) The changing structures of co-invention networks in American urban areas, *Procedia Computer Science*, 96(2016): 1075-1085.
34. Maggioni, M. A., Nosvelli, M., and Uberti, T. E. (2007). Space versus networks in the geography of innovation: A European analysis, *Papers in Regional Science*, 86(3): 471-493.
35. Maggioni, M. A., Nosvelli, M., and Uberti, T. E. (2007). Space versus networks in the geography of innovation: A European analysis, *Papers in Regional Science*, 86(3): 471-493.
36. Maskell, P. and Malmberg, A. (1999). Localised learning and industrial competitiveness, *Cambridge Journal of Economics*, 23(2): 167-185.
37. McKelvey, M., Alm, H., and Riccaboni, M. (2003). Does co-location matter for formal knowledge collaboration in the Swedish biotechnology-pharmaceutical sector? *Research Policy*, 32: 483-501.
38. Nelson, R. R. and Winter, S.G. (1982). *An evolutionary theory of economic change*. Cambridge, MA: Harvard University Press.
39. Ó hUallacháin, B. and Lee, D. S. (2014). Urban centers and networks of co-invention in American biotechnology, *The Annals of Regional Science*, 52(3): 613-636.
40. Organization for Economic Co-operation and Development (OECD). Definition of Functional Urban Areas (FUA) for the OECD metropolitan database. Accessed 25 Dec. 2016.
41. Polanyi, M. (1996). The logic of tacit inference, *Philosophy*, 41(155): 1-18.
42. Ponds, R., von Oort, F., and Frenken, K. (2007). The geographical and institutional proximity of research collaboration, *Papers in Regional Science*, 86(3): 423-443.
43. Rondé, P. and Hussler, C. (2005). Innovation in regions: What does really matter? *Research Policy*, 34: 1150-1172.
44. Salazar, A., Haackney, R., and Howells, J. (2003). The strategic impact of internet technology in biotechnology and pharmaceutical firms: insights from a knowledge management perspective, *Information Technology and Management*, 4(2): 289-301.
45. Saxenian, A. and Hsu, J. Y. (2001). The Silicon Valley—Hsinchu connection: technical communities and industrial upgrading, *Industrial and Corporate Change*, 10(4): 893-920.
46. Scott, J. (2000). *Social Network Analysis: A Handbook*. London: Sage Publications.

47. Simmie, J. (2003). Innovation and urban regions as national and international nodes for the transfer and sharing of knowledge, *Regional Studies*, 37(6-7): 607-20.
48. Torre, A. and Rallet, A. (2005). Proximity and localization, *Regional Studies*, 39 (1): 47-59.
49. U.S. Bureau of Economic Analysis (BEA). Sources of regional data. Accessed 23 Dec. 2016.
50. U.S. Office of Management and Budget (OMB). List of Metropolitan Statistical Areas. Accessed 10 Jan. 2017.
51. U.S. Patent and Trademark Office. USPTO Patent full-text and image database. Retrieved from http://patft.uspto.gov/netahtm1/PTO/search-adv.htm. Accessed 23 Feb. 2017.
52. Vallance, P. (2007). Rethinking economic geographies of knowledge, *Geography Compass*, 1(4): 797-813.
53. Varga, A. (2000). Local academic knowledge spillovers and the concentration of economic activity, *Journal of Regional Science*, 40: 289-309.
54. Wasserman, S. and Faust, K. (1994). *Social Network Analysis: Methods and Application*. Cambridge, New York: Cambridge University Press.
55. Yeung, H. W. C. (2005). Rethinking relational economic geography, *Transactions of the Institute of British Geographers*, 30: 37-51.