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Tell Me Who You Patent With and I'll Tell You Who You Are: Evidence from Inter-Regional Patenting Networks in Three Emerging Technological Fields

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ABSTRACT

This paper presents an overview of co-patenting trends at the national and regional level in three technology fields (biotechnology, telecommunications and renewable energy), across regions in the OECD and emerging economies, from the late 1970s to the late 2000s. After a general introduction on regional patenting activities, inter-regional co-inventorship networks in the three selected technologies are built and analysed. Different behaviors and relative network positioning emerge, in terms of top patenting regions both across technological fields and over time. Co-patenting networks increase their density over time and they show preferential attachment properties, namely regions with a central position in an early phase of development of the network tend to maintain their positioning in the future. However, there are also windows of opportunity for new central nodes to emerge in the network. Evidence shows that the structure of the network evolves differently depending on technological field and that the role of spatial proximity and capability proximity is mixed in influencing co-inventorship patterns. Co-patenting networks include star players that establish connections regardless of the proximity of partners; but also several well-performing actors that benefit from proximity or relative proximity of agents.

Cet article analyse des réseaux de co-brevets parmi les régions des pays OCDE et des économies émergentes sélectionnées, dans trois secteurs technologiques (télécommunications, biotechnologie, énergie renouvelable) sur la période 1977-2007. Après une introduction générale sur la production de brevets à niveau régional, les réseaux inter-régionaux de co-brevets dans les trois technologies sont construits et analysés. Des comportements et des positionnements différents à niveau des régions émergent, dans la structure générale des réseaux analysés, selon la technologie et dans le temps. Les réseaux de co-brevets deviennent plus denses avec le temps et montrent la propriété de l'attachement préférentiel, soit les régions avec une position centrale dans le réseau au début tendent à la garder dans le temps. Toutefois, il existe des opportunités pour atteindre un positionnement central même pour les régions qui entrent dans le réseau dans des phases successives. Les données montrent comment la structure du réseau évolue avec des caractéristiques différentes selon la classe technologique et comment la proximité spatiale et la proximité des connaissances influencent l'évolution du phénomène de la co-invention des brevets : les réseaux d'excellence contiennent les acteurs leaders, qui établissent leurs collaborations innovantes sans tenir en compte la proximité géographique, ainsi que plusieurs acteurs performants qui bénéficient aussi de la proximité géographique relative avec autres agents.

Keywords: regional innovation, patents, co-inventorship, network analysis, ICT, green technologies, biotechnology

JEL codes: O1, O3, O25, R12, D85, L00

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TELL ME WHO YOU PATENT WITH AND I'LL TELL YOU WHO YOU ARE
Evidence from inter-regional patenting networks in three emerging technological fields

Giulia Ajmone Marsan[*] and Annalisa Primi[♣]

1. INTRODUCTION[1]

Networks are increasingly important for innovation. This is true both for the creation of scientific knowledge, where research is more and more carried out by teams of scientists and researchers, often located in different places, and in the business sphere, where firms are experimenting with new ways of partnering with others (firms, research centres and customers) for getting a head start in the market (OECD, 2010a).

For decades, economists have been showing the relevance of collaborative arrangements for the production and dissemination of new knowledge. The density and quality of innovation systems have proven to be key variables in explaining the capacity of socio-economic systems (local, regional or national) to generate knowledge and introduce new products, processes or services, to markets and users (Freeman, 1982; Nelson, 1993; OECD, 1999). The successes of many industrial poles, clusters and districts have proven that there were economies generated by co-location and proximity to customers and suppliers. However, today there is something new, which makes networks increasingly relevant for innovation:

- **New technological paradigms** have both increased the speed at which connectivity can take place and multiplied the number of potential partners by facilitating collaborations between "distant" actors. They have made it possible to establish business contacts and share information, more than ever before, regardless of the location of the selected partners.

- **The globalisation process** has increased the need and profitability of accessing external sources of information for innovation. For example, it allows for a better understanding of foreign and distant customer markets. Globalisation has also amplified the number and geographical distribution of potential partners. Today, distance in competences and skills could be higher barriers for collaboration than geographical distance. This is shown by the increasing international collaboration in research and development and in innovation.

- **Participation in networks** is not only leapfrog with respect to competences or to make up for internal weaknesses (i.e. I partner with you because I need you); but it is also valued for the increasing returns it can deliver to the partners (i.e. I partner with you, because with you my performance is superior). Such increasing returns are due to greater knowledge about new markets, pooling of resources, diversification of activities and risk sharing. Innovation surveys reveal that the firms participating in innovation networks and carrying out collaborative innovation projects tend to spend more on innovation than those that do not. This suggests that collaboration tends to be used as a complement to increase innovative

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potential, rather than as a substitution for in-house investment (OECD, 2010b; Cimoli, Primi, Rovira, 2011).

The new innovation scenario, coupled with the growing pressure for the majority of the countries to find new sources of growth, as well as to innovate to address social and economic challenges, is putting great pressure on firms to find new drivers for competitiveness. Increasingly, firms value competitiveness based on quality, capacity to provide customised solutions and to respond to emerging demands, over price-driven competition. In addition, scientific research is called upon to provide responses to global challenges, like environmental sustainability, and this research process is increasingly carried out through complex linkages between local agents (research centres, or universities for example) and partners abroad. This new scenario in which the geography of innovation is changing, reshaping local and global linkages, is giving new roles to sub-national territories (regions) as main agents of change in national innovation systems. Firms, research institutions and individuals are located and interact within and between regions for innovating. They are developing new business models, to respond to the reshaping of the production and innovation space, driven by globalisation and the new technological paradigms. The evolution of collaboration patterns of agents located in different regions can help identify emerging trends in the geography of innovation (who collaborates with whom).

After providing a general overview on patenting activity in different technologies, at the national and sub-national level, this paper presents an exploratory study to identify regional trends in innovation networks, by focusing on co-inventorship patterns between regions.

The use of patents as an innovation indicator has been discussed for a long time in the literature (Grilliches, 1990), while the analysis of co-inventorship patterns and patent citations is a more recent topic (Jaffe and Trajtenberg, 1998; Breschi and Lissoni, 2001; Paci and Usai, 2009). Patents, like developing complementary manufacturing capacities or using trade secrets and trademarks, are one of the appropriability mechanisms that firms and other types of institutions use to protect their innovations. They can be registered under multiple inventor names, when the innovation is the result of a collaborative research project. Beyond some limitations, it is fairly accepted that patents provide useful information about innovative efforts in given technological fields, and that they convey insights into the patterns of collaboration in research between agents, when multiple inventors are listed in a patent document. Some technological avenues are more patent intensive than others, like electronics, ICT, pharmaceuticals, and biotechnology, among others, and in those sectors patenting trends convey information about innovation strategies and behaviour of firms.

The three technology fields used in this analysis are: biotechnology, telecommunications and renewable energy.[2] The sectors have been chosen both for their relative importance of sectoral patenting (as in the case of biotechnology and telecommunications) and for their growing relevance in national and regional innovation policy agendas; in fact, there is a rising interest in new and greener sources of energy (OECD, 2011a). In addition, those three technological fields are characterised by different market structures (for example, a different mix of small and large firms), heterogeneous relevance of external sources of information for innovation, different proximity with the scientific sector and varied patterns of collaboration between firms and research institutions for innovation. This variety entails different forms of organisation of the inventive activity in a territory, making the comparative analysis highly interesting form the regional/territorial point of view.

[2] Patents in telecommunications and biotechnology are identified according to the 8th edition of the International Patent Classification (IPC); for the list of included technologies *see http://www.oecd.org/dataoecd/34/34/40807441.pdf*. Patents in "Renewable Energies" include patents in Renewable Energy Generation Technologies, as identified by the OECD. For more details, see: *http://www.oecd.org/dataoecd/42/51/44387201.pdf*.

The choice of regions as the unit of analysis for co-inventorship patterns is an unusual one. Available studies tend to focus on cross-country comparisons (The Royal Society, 2011) or on micro-level studies that look at the network of inventors within a country or in a specific region, by taking as the unit of analysis the inventors or the institutions to which inventors are affiliated (Fleming. Mingo and Chen, 2007; Graf, 2008; Al-Laham and Amburgey, 2010). Regional co-inventorship patterns offer an intermediary point of view which complements the evidence at the country and individual level. The regional analysis allows characterisations of regional innovation systems by contributing to understand the behaviour and the trajectory of industries located in specific places. Hence, this paper is an important piece of evidence that complements country and individual level analysis.

This paper is structured as follows: the first and second sections present an overview of patenting trends at the national and regional level in three technology fields (biotechnology, telecommunications and renewable energy). Stylised facts show the rise in patenting and its concentration in a few world leading regions, located both in top patenting countries (such as the US and Germany) and in less patenting-intensive ones (such as China and Spain). Differences emerge in terms of top patenting regions across technological fields; even if certain regions perform as global hubs for knowledge generation, regardless of the technological field, such as California, or Baden-Württemberg. The second section focuses on the variety of co-inventorship models between inventors located in different regions. The third section shows evidence about regional co-inventorship networks using social network analysis techniques (Watts and Strogatz, 1998; Barabasi et al., 2002). As network density increases over time, regional co-inventorship networks show preferential attachment properties, so regions with a central position in an early phase of development of the network tend to maintain their positioning in the future. However, there are also windows of opportunity for new central nodes to emerge in the network. The fourth section concludes by providing some preliminary policy implications and future directions for research.

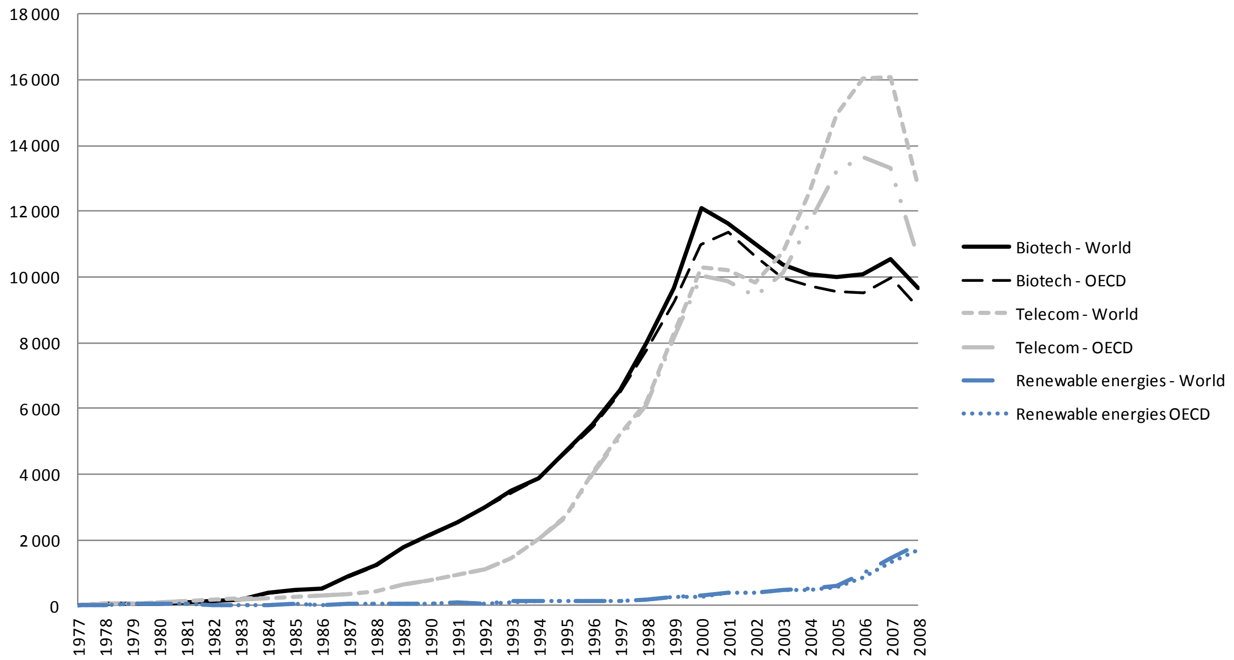
2. PATENTING TRENDS IN THREE TECHNOLOGY FIELDS

Three major issues characterise global trends in patenting from the late 1970s up to the present. ***First, there is a rise in patent applications***. The increase in world patent applications and the "patent boom" of the end of the 1990s is a well known and documented phenomenon (Kortum and Lerner, 1998; OECD, 2004; Cimoli and Primi, 2009). As Figure 9 in Annex II shows, the number of total PCT patent applications through the European Patent Office (EPO) grew from a yearly average of 7 500 in the decade of the 1980s, to 45 000 in the 1990s to 130 000 in the 2000s.

Secondly, there are sectoral differences in patent trends. Patenting behaviour follows specific sectoral patterns (Cohen, Nelson and Walsh, 2000). For example, in telecommunications there has been a boom in the early 2000s: patent applications rose from a yearly average of 1 000 in the first half of the decade of the 1990s to 11 000 in the first half of the decade of 2000s. The biotechnology field followed a different trend, with patent applications rising steadily up to the end of the 1990s and stabilising around a yearly average of 10 000 patent applications in the 2000s (see Figure 1). Of the three sectors studied in this paper, the renewable energy field has been growing the least, and began to show certain dynamism only in recent years, due to the growing concerns about the economic sustainability of current energy consumption and provision trends. In the late 1970s, renewable energy was as patent intensive as the other technological fields, while later, the gap with telecom and biotech exploded. In the first half of the 1980s, there were around 40 yearly patent applications in the renewable energy field, growing to around 400 per year in the first half of 2000s. The heterogeneity in the evolution of sectoral patenting trends is revealed also by the changes in the share of sectoral patents over total patent applications (see Table 1).

Figure 1. Number of PCT patent applications by technology field

Biotech, telecom, renewable energy



Note: Patents applied via the Patent Co-operation Treaty (PCT) follow an international procedure, which allows inventors to file pre-applications to many offices world-wide. Therefore, in order to consider patent application with an international dimension, only PCT patents are taken into account. Priority years (i.e. the year of first filing a patent, the closest to the actual date of invention) are considered.

Source: Authors' elaboration on the basis of the OECD Patent Database and the OECD Regional Patent Database.

Table 1. Share of PCT patent applications by technology field over total patent applications

1977-2007 (in percents)

	1977-1979	1985-1987	1995-1997	2005-2007
Biotechnology	3.26	7.27	10.52	6.74
Telecommunications	2.67	3.82	7.40	10.36
Renewable energy	2.19	0.47	0.27	0.66

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Third, different countries lead in the different technology fields and new countries are entering the scene as major players in global patenting (see Table 2, 3 and 4). The US was, and is, the leading patenting country in all three technological paradigms, and it maintains its global leadership over time. However its share declines over time, due to the entrance of new actors in the global patent game. For example, the US accounted for around 50% of world patent applications in biotech and telecom in the late 1970s, while today it accounts for 44% and 31% respectively. In the renewable energy field, the US was responsible for 57% of total patent applications in the 1970s and it now accounts for 23%. The reduction in the world share of US patenting, despite the increase in the absolute numbers of patents applied for, is explained by the emergence of new countries as patent leaders. A notable case is that of Korea. The rise of Korea as the 8th patenting country in biotechnology, 4th in telecom and 9th in renewable energy in less than three decades is one of the indicators of the successful catching-up strategy of a country, which invested continuously in the creation of industrial and technological capabilities in key technological fields, since the late 1960s.

Table 2. Top ten patenting countries - Biotechnology

PCT, 1977-1979/2005-2007

Biotechnology				
Ranking	1977-1979	%	2005-2007	%
1	United States	50.54	United States	43.84
2	Japan	10.17	Japan	12.37
3	Sweden	7.63	Germany	7.13
4	United Kingdom	6.10	United Kingdom	4.45
5	Germany	5.93	France	3.59
6	France	5.08	Canada	3.01
7	Switzerland	4.24	Netherlands	2.54
8	Denmark	4.24	Korea	2.53
9	Australia	3.39	Australia	1.99
10	Netherlands	1.27	Switzerland	1.79
	Cumulative share (%)	98.59		83.24
Top 10	Number of patents	116		25 472

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 3. Top ten patenting countries - Telecommunications

PCT, 1977-1979/2005-2007

Telecommunications				
Ranking	1977-1979	%	2005-2007	%
1	United States	51.34	United States	30.66
2	Japan	16.96	Japan	15.71
3	Sweden	8.93	China	12.58
4	United Kingdom	4.46	Korea	6.86
5	Germany	3.57	Germany	6.02
6	Netherlands	3.57	France	4.04
7	Switzerland	3.13	Sweden	3.77
8	Australia	2.68	United Kingdom	3.69
9	France	1.79	Finland	3.44
10	Austria	0.89	Canada	2.87
	Cumulative share (%)	97.32		89.62
Top 10	Number of patents	109		42 175

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 4. Top ten patenting countries – Renewable energy

PCT, 1977-1979/2005-2007

Renewable energy				
Ranking	1977-1979	%	2005-2007	%
1	United States	56.76	United States	22.67
2	Sweden	13.51	Germany	12.48
3	Switzerland	9.46	Japan	9.31
4	Germany	5.41	Denmark	5.56
5	Australia	3.72	Spain	5.55
6	United Kingdom	2.70	United Kingdom	4.91
7	France	2.70	China	4.54
8	Japan	1.35	Italy	3.94
9	Norway	1.35	Korea	3.86
10	Netherlands	1.35	France	3.38
	Cumulative share (%)	98.31		76.20
Top 10	Number of patents	73		2 317

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

3. PATENTING TRENDS AT THE SUB-NATIONAL LEVEL

But what do national data hide? A look at patent applications by region enriches the description of world patenting trends. It highlights "*where*" in each country the patenting activity is concentrated (due to the localisation of firms and industrial and scientific complexes) and it reveals highly patent-intensive locations which "disappear" when looking at country level data only.

The regional patent data used in this paper comes from the OECD REGPAT database, a newly released database containing patent applications filed through EPO and the respective location of inventors.[3] The database contains information about patenting active regions starting from 1977.[4] The analysis is carried out using the cumulative number of PCT patents applied for via the EPO in four different periods: 1977-1979, 1985-1987, 1995-1997 and 2005-2007. The three-year period has been chosen to smooth yearly fluctuations in patent applications.

The analysis of patent applications by region in the three selected technological fields confirms the global trends, but highlights different hot spots for innovation at the global level, which are hidden by country data. Regional patent data highlight two major trends:

i. The repositioning of actors (i.e. regions) in the patent game (as illustrated by changes in the ranking of the top 20 patenting regions across time);
ii. The entrance of new actors (i.e. regions) in the knowledge game (as illustrated by the entry of new regions in the top 20 list and by the decreasing cumulative share of top 20 patenting regions over total patenting).

Telecom

In the telecommunications sector (Figure 2), the top 20 patenting regions accounted for respectively 78%, 72%, 66% and 67% of total patent applications, in the four analyzed periods. This decreasing trend reflects the entrance of new regions in sectoral patenting.

At the same time, different regions follow different patterns. Some regions have reduced their share in total patenting over time, indicating a reduced "market-related innovativeness". For example, Stockholm in the late 1970s accounted for 5.5% of total patent applications, ranking the sixth world patenting region, however in the period 2005-2007, its regional share had declined to 1.9% and the region's rank to 11th. This might be explained by a recession in the IT and telecom sector in Sweden and specific business challenges of the large firms involved in the sector[5]. Other regions are stable, like Ile-de-France, which accounts steadily for around 2% of total telecom patent applications since the 1980s.

The emergence of new regions as dominant players such as Guangdong (China) and the Korean Capital Region is an interesting phenomenon. Neither was among the top patenting players in the previous periods; however in 2005-07 they were, respectively, the second and the fourth, among the top 20 patenting regions, accounting for 10% and 5.3% of total patenting.[6] For Seoul, this is the result of the

[3] Regions are defined following the OECD classifications as TL2, which is the first sub-national entity in each State, i.e. states in Federations, regions in Italy, Autonomous Communities in Spain, etc. The database also contains information at the TL3 level. Data at the TL3 level have not been explored for this paper, since the objective was to provide an overview of cross-regional co-inventorship patterns at the larger regional scale. For detailed information about the OECD Regpat Database see: Maraut et al., 2008.

[4] Patents are classified by priority date, regionalised according the address of the inventor (and not the applicant since the former better reflects where the innovative activity takes place) and assigned to regions by fractional counts.

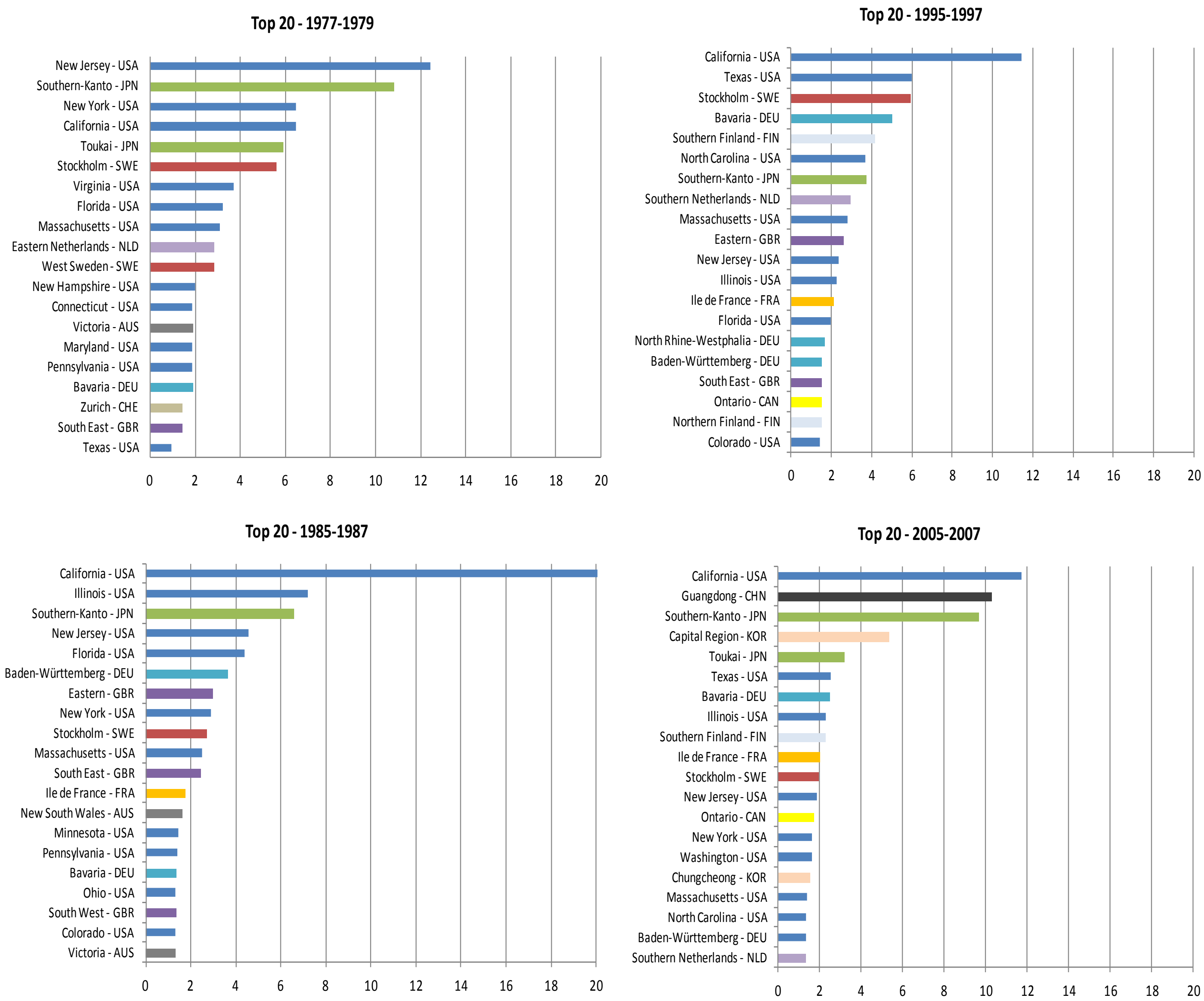
[5] See VINNOVA, 2004 for an analysis on the evolution of the telecom sector in Sweden from the 1970s to the beginning of 2000s.

[6] See Fan, 2006 for an analysis of the technological catching-up of Chinese manufacturing firms in the telecom-equipment industry and Lee and Lim, 2001 for the catching-up in the Korean industries.

development of the IT sector prioritised by national industrial and technology policy. In the case of China, the rise in patenting follows the incipient efforts of a shift from a pattern of imitation towards one of innovation, in the national industry. California shows an interesting evolution as well. In the late 1970s, it was the fourth patenting region, accounting for 6.5% of total patenting. The mid 1980s marked the boom of the telecom industry in California and the region jumped to first place in the world, accounting for 20% of total world patenting. The patent dynamism of California in the sector is largely explained by the unique Silicon Valley phenomenon.[7] Since the late 1990s, California has consolidated its position as the global leader in telecom patenting, as the industry reconfigured itself and several actors emerged (like Asian regions), and others declined (like the Swedish Capital Region).

Figure 2. Top 20 patenting regions in telecommunications

Regional share over total PCT applications (in %)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

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[7] See Hall and Markusen, 1985 for an early assessment of the Silicon Valley phenomenon.

Biotech

The biotechnology sector (see Figure 10 in Annex II) also shows a reduction in the concentration of patenting and a repositioning of key regional players. Top 20 patenting regions accounted for 75% of total patent applications in the late 1970s, and this share declined to 52% by 2005-07. Massachusetts, New York and Southern Kanto were the top three patenting regions in the late 1970s, accounting respectively for 8.4%, 8.1% and 6.4% of total patent applications. In the latest period, the top three patenting regions are California, Southern Kanto and Massachusetts, which account respectively for 11.2%, 6.6% and 5.3%.

The changes in the relative positioning of regions in global patenting can be related to location choices of firms and research centres in the country, as well as to policies supporting the development of capabilities and infrastructure in specific places at given moments in time. For example, in the case of the biotechnology, it is interesting to note the late, but successful development of industrial capabilities in Germany. In the 1970s, no German region was appearing in the top 20, whereas by the late 1990s, 3 out of top 20 patenting regions are from Germany. The catching-up of German regions in biotechnology may be related to a targeted policy programme introduced in the mid 1990s by the Federal Ministry for Education and Research called BioRegio.[8] The programme opened a competition among regions to access funding to support applied research in biotechnology and to foster collaboration among firms, universities and research centres. Patenting in Korea's Capital Region shows the technological catch up of the country. Also the development of Korea's biotech industry has been the result of targeted policies. Since the 1980s the Korean Government invested in R&D, infrastructure and human capital capabilities in the biotechnology industry to support the development of a national industrial base in the field[9].

Regional biotechnology patenting is mostly dominated by large regions, although there are exceptions, like Denmark's Capital Region and Western Netherlands. The Denmark Capital Region is an interesting case. The region has been among the top world biotechnology patenting players since the late 1970s; it accounts today for 1.4% of total word patent applications and it ranks 14th among the top 20.[10]

Renewable energy

The renewable energy field (Figure 11 in Annex II) confirms this trend towards a reduction in concentration of patenting by region. Top 20 patenting regions accounted for 77% of total patent applications in the late 1970s, and 42% in the late 2000s. The most remarkable trend in this field is the reshuffling of top regional players. In the beginning, the technology field was dominated by US states (13 out of the top 20) and Swedish regions (3 out of the top 20). More recently, the top 20 includes regions from 12 different countries: from the US, to Japan, Denmark and Germany. Swedish regions lost their relative advantage over time.[11] In Danish regions, instead, successful iterative knowledge transfer mechanisms between companies and research institutions have fostered the regional actors to become global players in the renewable energy industry.[12] The case of Navarra is also interesting. This Spanish

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[8] For more information on the BioRegio programme see:

http://www.nature.com/bioent/bioenews/102004/full/bioent833.html#refs.

[9] For an overview on Korean investments in the biotech sector during the 1980s and the 1990s see Choi *et al.*, 1999.

[10] For more information on the Greater Copenhagen biotech cluster see, for example, Bloch, 2004 or and Coenen, Moodysson and Asheim, 2004.

[11] According to Jacobsson and Bergek, 2004, a mix of hesitant policies and various blocking mechanisms made Sweden lose its initial advantage in renewable energy technologies.

[12] See Garud and Karnoe, 2003 and Kamp *et al.,* 2004 for an analysis of the development of the renewable technology and industry in Denmark.

Autonomous Community accounts for 1.1% of total patenting in the field and ranks 15th, even though it belongs to a less patent-intensive country. The catching-up of Navarra in renewable energy can be related to a successful combination of local government vision, institutional support, private sector commitment and engagement of the local community in industry development. The rise of this industry, which has benefited from a high level of tax incentives and direct financing, contributed to the creation of high-quality jobs in the region.[13] The fact that this technology is characterised by a greater variety of regions coming from different countries in the top 20 might be explained by the linkage between the technological development in the renewable energy field and the place-based natural assets present in the regions.

4. REGIONAL OPENNESS: VARIETY IN CO-INVENTORSHIP MODELS OF TOP PATENTING REGIONS

In recent years, not only has there been a rise in patent intensity across all technology fields, but patenting behaviour has also changed. International and inter-regional collaboration in patenting have been on the rising. With globalisation and the diffusion of new communication technologies, there has been an upsurge in collaboration patterns among partners located in different territories (OECD, 2011b). This trend is largely heterogeneous across technological fields and countries (See Figure 3 and 4).

During the last three decades, the share of patent applications with multiple co-inventors located in at least two different regions rose from 10% to 20%, against the backdrop of a sharp increase in patent activity. Significant differences between technologies emerge. Biotechnology shows the highest share of cross-regional patenting. In the late 1970s, 16.8% of total patents had at least two co-inventors from different regions, and this share rose to 30.8% in 2005-2007. In telecommunications and renewable energy, this share is lower, even though in both fields it more than doubled over last three decades: from 7.9% to 16.2% in telecom and from 7.2% to 14.6% in renewable energy. This heterogeneity of trends across different technological fields reflects an evolution in the spatial organisation of industries and the differences in the nature of the research process involved.

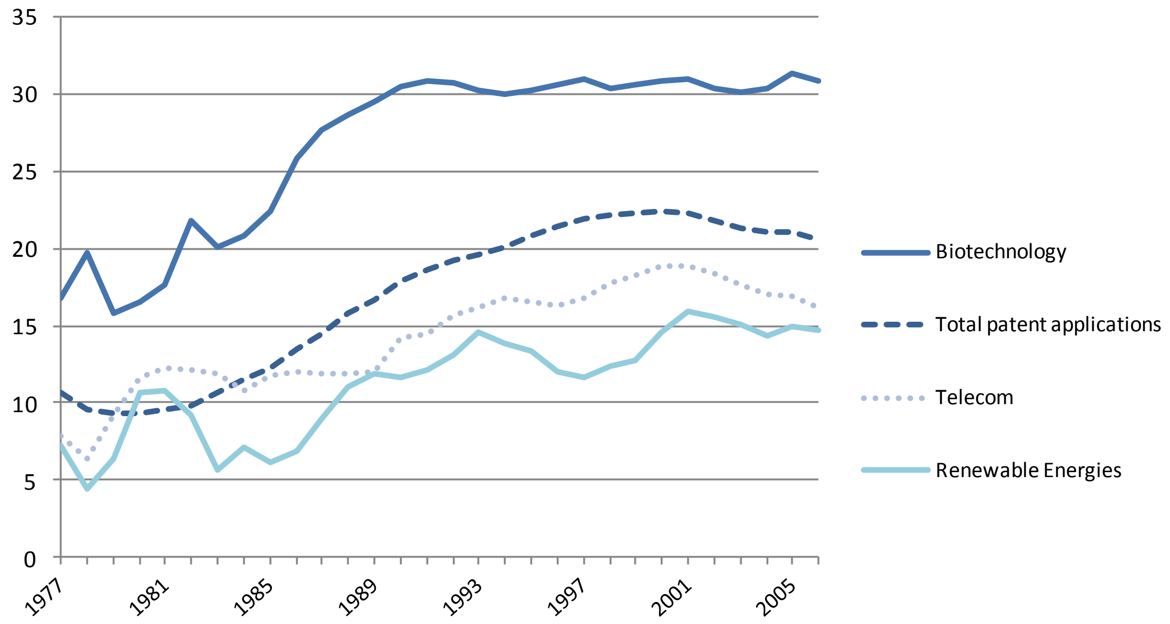
The propensity of patenting agents located in a given region to have co-inventors coming from other regions is shaped by several factors. The institutional framework of the country to which the region belongs is one factor. Another factor is the geographical size of countries and regions, namely that small countries and regions tend to easily establish cross-border connections. Possible explanations are the geographical proximity to inventors located in other regions or countries and the need to collaborate with researchers elsewhere, due to the possible lack of resources for innovation, in their own region. Policy incentives may also play a role.

In Germany and the US, the share of co-patent application rose from 30% to 60% and from 20% to 51% in the last three decades, respectively. Japan is a peculiar case, since the share of patent applications with inventors coming from two different regions increased from 18% to 30% from late 1970s to the early 1990s, and then declined to 16% in the late 2000s.

[13] Faulin *at al.* (2006) offer an interesting review of the experience of Navarra in renewable energy development.

Figure 3. Co-inventorship by technological field

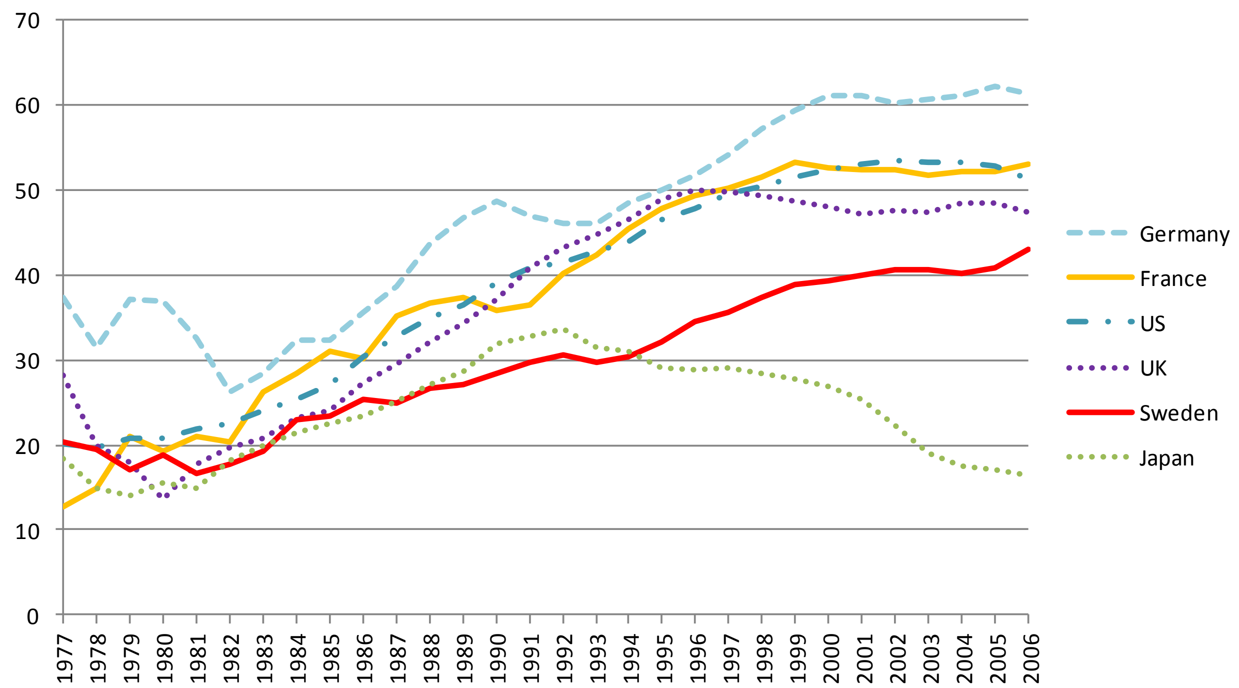
Share of patent applications with at least two co-inventors from two different regions as a % of total patent applications, three-year moving average (1977-2007)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 4. Co-inventorship by country

Share of patent applications with at least two co-inventors from two different regions as a % of total patent applications, three-year moving average (1977-2007)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

In order to illustrate the variety in models of co-inventorship, tools from social network analysis have been used.[14] A network can be defined as a set of interconnected elements (the nodes) in which the links between nodes represent a specific form of relationship. In the case of co-inventorship networks, the nodes are the regions, where the inventors are located, and the links are the patents, which have been co-invented by people located in the corresponding regions. In other words, region A will be linked to region B if and only if there is at least one patent, which has at least one inventor from each of the two regions.[15]

Figures 5, 6 and 7 show the variety in regional co-inventorship among the top 20 patenting regions for 2005-07 in the three fields: biotechnology, telecommunications and renewable energy. They show, for each region, the share of patents with at least a co-inventor not located in the same region and the network degree.[16] Each figure defines the co-inventorship space by the *intensity of co-patenting* (i.e. the share of patent applications with at least one co-inventor coming from a different region over the total of all patent applications) on the vertical axis, and *the extensiveness of co-patenting*, measured by the degree of the nodes in the network (i.e., the variety of other regions with which each region is linked by means of co-patenting), on the horizontal axis. Bubble sizes represent the share of regional patenting over total sectoral patenting worldwide. Because of the volatility in patenting intensity of regions that are not top players, the analysis refers to top patenting regions only. In addition, since only top performing regions are taken into account, the analysis looks at the quantity and the type of collaboration regardless of region size, in order to measure the effective intensity of collaborations for each of the top 20 patenting hubs, in different technologies.

The co-inventorship space, defined by the intensity and the extensiveness of the phenomenon, shows clear sectoral and regional patterns in co-patenting openness:

- There is no linear relationship between intensity and extensiveness of regional openness in co-inventorship and innovation performance. The top 20 patenting regions in each technological field show different co-inventorship models, some highly intensive in inter-regional patenting, and others less intensive in inter-regional collaboration.
- Secondly, there are marked sectoral differences in co-inventorship intensity. Biotechnology is the sector with the highest average co-inventorship intensity of the three sectors analysed.
- Thirdly, there are clear "macro-regional" or country effects.

California, and, in the case of biotechnology, also Massachusetts, are outliers in the extensiveness of their openness. Those regions have a relatively low intensity of extra-regional co-inventorship: this is quite intuitive considering their size and their global role for location of leading firms and research centres. However, they are the most open in terms of variety of regional partners. California plays the role of a global hub which is able to attract firms and researchers from all over the world, and, at the same time, it maintains a network of global relations, mostly explained by the fact that there is a high demand for collaborating with the top player.

Top patenting regions from Asian countries tend to have lower co-inventorship intensity and lower openness in all technological paradigms. A series of factors may explain this trend, such as the cultural and geographic distance which might influence the lower level of openness of Asian patenting. Some top

[14] For a detailed description of social network indicators see Annex 1.

[15] In this paper, we consider two regions as linked by a co-inventorship relationship only if they shared more than 3 co-patents for each period, so as to exclude sporadic collaborations.

[16] The degree of the nodes is the number of links which connect each node to other nodes; it shows the relative importance of each node (i.e. region) in the network. In our case, the degree represents the number of regions with which the node is linked by co-patenting relationships.

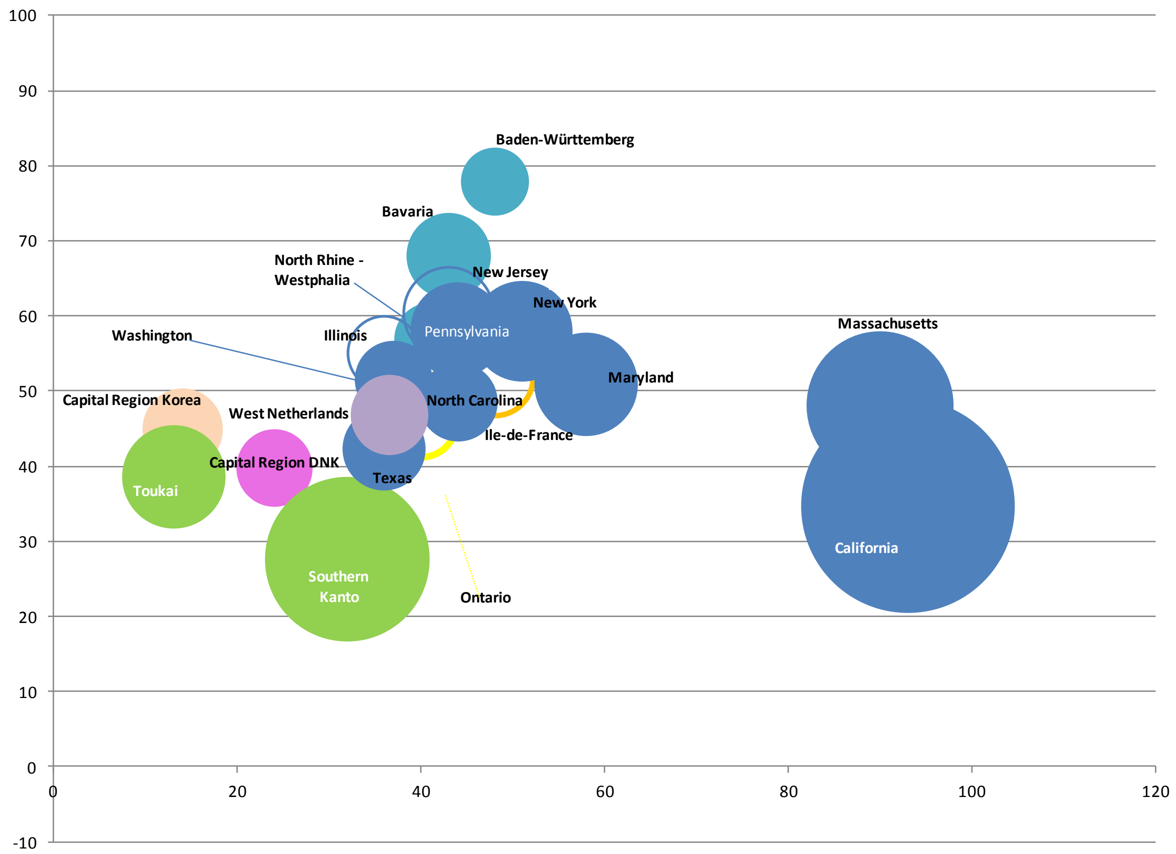
patenting Asian regions are nested in less technologically dense regional environments due to the late industrialisation and catching-up of those economies, thus reducing the availability of easily reachable top partners.

In contrast to the "Asian" model, European regions within the top 20 tend to show a high intensity of cross-regional co-inventorship and a middle level of openness in terms of the number of regional partners. This can be the result of several concurring factors: the geographic proximity of European regions, which have cross-borders partners within very low geographic distances; the role of the European Union; and the historical organisation of their industrial and scientific activities, characterised by the presence of several small competing hubs not usually dominated by one major industrial agglomeration.

Figure 5. Variety in regional co-inventorship models: biotechnology

2005-2007

Vertical axis: share of regional patent applications with at least one co-inventor located in a different region. ***Horizontal axis***: degree of regional co-inventorship network, i.e. the number of regions to which a certain region is connected through co-patenting (a rising degree value indicates a higher regional openness)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

The co-inventorship space of the top 20 patenting regions in biotechnology shows the co-existence of three different models:

- **Global leadership**, as in the case of California and Massachusetts, with an average intensity in co-inventorship (34.7% and 48.1% respectively of patents with at least one co-inventor from another region) and with the highest openness in terms of variety of regional partners (network degree 93 and 90, respectively).

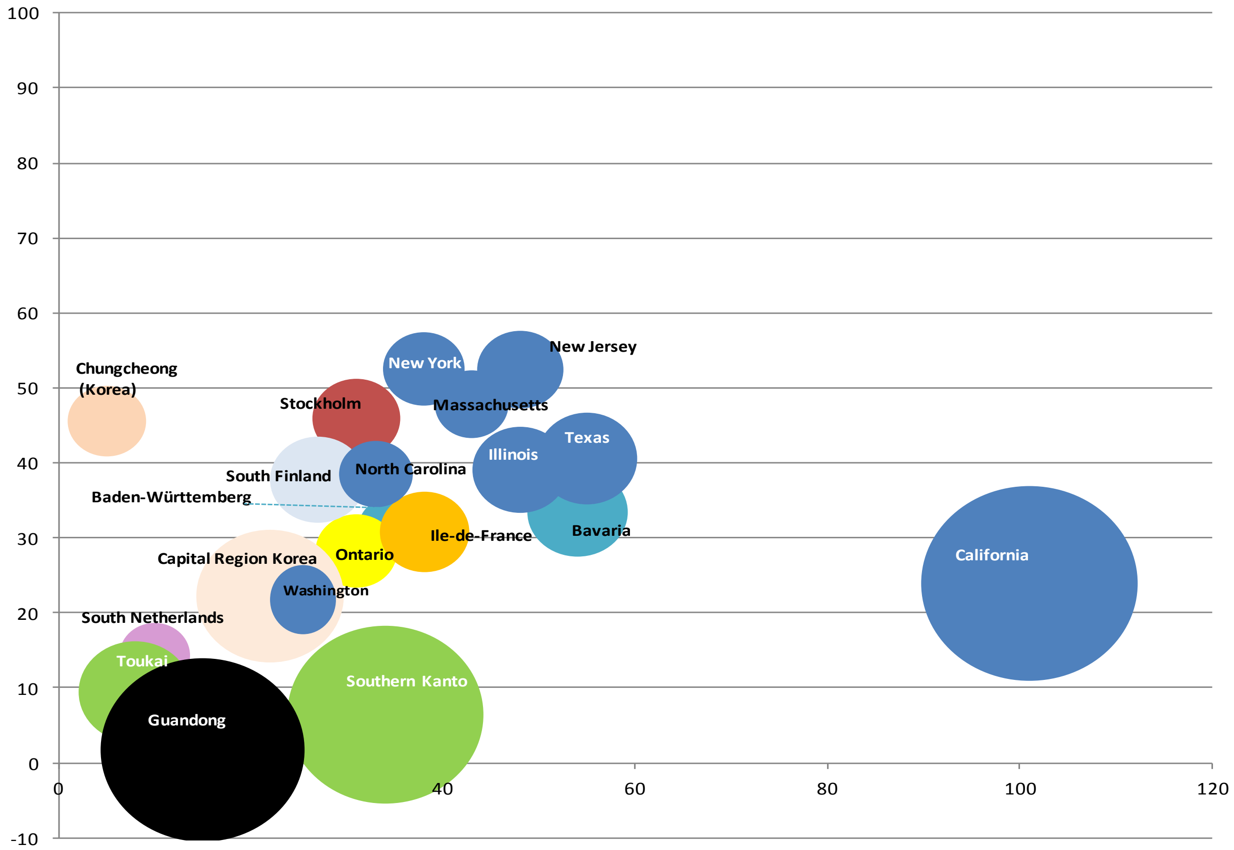
- The **team model**, which characterises the performance of German regions and some US states, as well as Ile-de-France and Ontario. These regions have co-inventorship intensity above the average (with Baden-Württemberg and Bavaria that possess the highest values: 78 % and 68% of patents with a co-inventor located in another region, respectively). These regions have all consolidated industrial and technological capabilities and developed durable collaboration patterns over time. Usually, they are nested in technologically dense territories making collaboration easier. In addition, many of them dispose of an institutional framework and territorial industrial organisation which favours linkages between different regions.

- **The catching-up model** characterises the situation of top-patenting Asian regions which experience the lowest levels both of co-inventorship intensity and extensiveness in openness. Southern Kanto, the second top patenting region in biotech, produces 27% of its patent applications with a co-inventor located in another region, and those inventors come from 32 different regions. The contrast with California is notable. This relatively closed model can be explained both by their cultural and geographical distance, by the competition between industries and by the late entrance of some of these regions in the technological field. One could assume that, while there will always be differences in intensity and degree of openness of co-inventorship networks, this less open behaviour will tend to disappear, as the regions consolidate their positioning in global market and become centres of reference for technological advancement worldwide. The Danish Capital Region has this same catching-up behaviour: 40% of patent applications involve a co-inventor located in another region, from 24 other regions.

Figure 6. Variety in regional co-inventorship models: telecom

2005-2007

Vertical axis: share of regional patent applications with at least one co-inventor located in a different region. ***Horizontal axis***: degree of regional co-inventorship network, i.e. the number of regions to which a certain region is connected through co-patenting (a rising degree value indicates a higher regional openness)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

In telecommunications, differences among regional co-inventorship models are more pronounced than in biotechnology. California continues to exhibit the global leadership collaborative model, with average co-inventorship intensity (24%) and an extremely high number of co-inventor regions (101)[17]. The catching-up model applies to two Japanese regions (Southern Kanto and Toukai) and the Chinese province of Guangdong. These regions are characterised by less than 10% of patent applications with a co-inventor located in another region and 34, 8 and 15 co-inventor regions, respectively. In this field, Korean regions (Capital and Chungcheong) are closer to the team model, as South Finland, the US and German regions. This can probably be explained by the advanced stage of development of the domestic industry in this technological field, in which Korea has already surpassed the catching-up phase.

The co-inventorship space of the top 20 patenting regions in renewable energy shows the peculiarities of this emerging and less patent-intensive field. First, **all top patenting regions display a catching-up model** in terms of openness. All regions, regardless of their co-inventorship intensity, are linked to a limited number of other regions. The most open region, California, has a degree value of 10 (ten times less

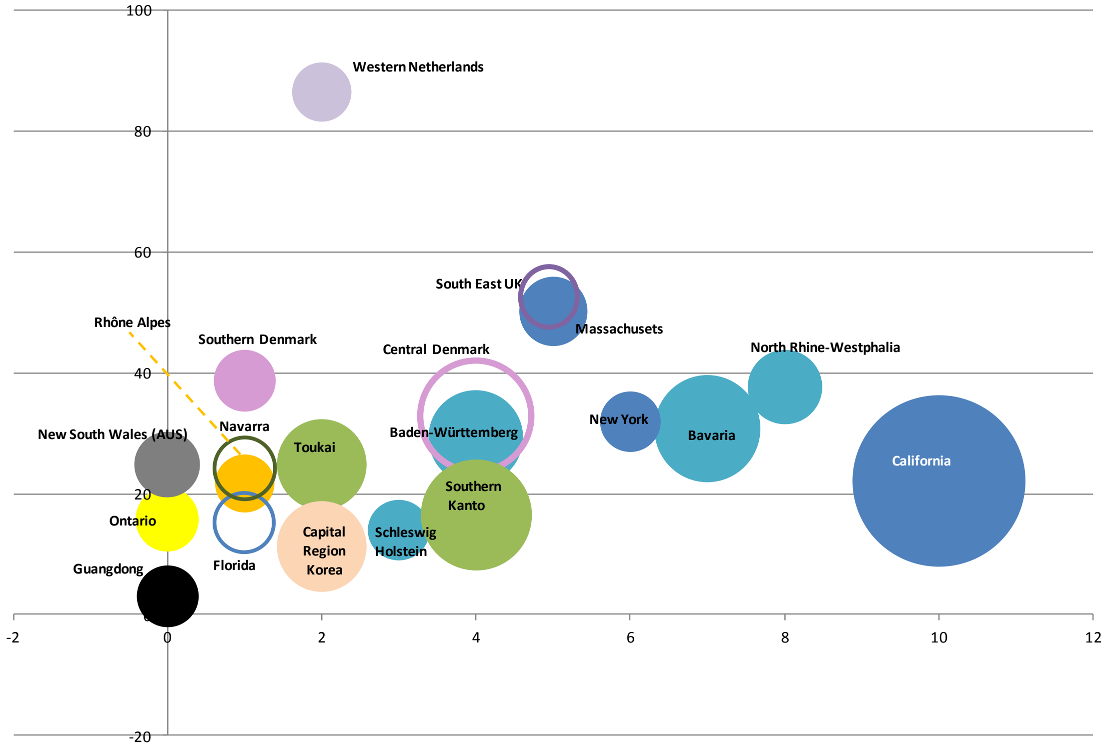
[17] See Saxenian, 1991 for a description of the dynamics of production networks in Silicon Valley.

than in the case of telecommunications, for instance). In this technological field, all patenting-intensive regions are still in the experimentation and catching-up phases. Western Netherland exhibits a peculiar behaviour: this region shows the highest share of patents with co-inventors form other regions (86%). This may be explained by a size effect: probably, given the small size of the region, inventors located there need to collaborate with partner elsewhere for research and development. Many regions show an average co-inventorship intensity such as Central and Southern Denmark (33% and 38% respectively); the German regions of Bavaria, Baden-Württemberg and North Rhine Westphalia, whose co-inventorship intensity varies between 30% and 40%, and Navarra (Spain) with a co-inventorship intensity of 24%. The Chinese province of Guangdong shows the lowest intensity (3%) followed by the Korean Capital Region (11%).

Figure 7. Variety in regional co-inventorship models: renewable energy

2005-2007

Vertical axis: share of regional patent applications with at least one co-inventor located in a different region. ***Horizontal axis***: degree of regional co-inventorship network. i.e. number of regions to which a certain region is connected through co-patenting (a rising degree value indicates a higher regional openness)



Note: Guangdong is among the top 20 top patenting regions in renewable energy, however, it exhibits a much less open behaviour than its peers: the degree of regional co-inventorship is the lowest and the share of patent applications with inventors located in other regions is only 3%.

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Tables 5, and 7 and 8 in Annex II illustrate the propensity of inventors in the top 20 regions to establish extra-regional collaborations[18] within the same country or elsewhere, in the three technologies selected. The geography of inter-regional co-patenting intensity is affected by several factors. They

[18] Data in Tables 5, 7 and 8 describe how the share of patent applications with inventors located in other regions is divided among geographical areas, namely whether these inventors from outside the region are located mainly in the same country, the same continent or elsewhere. These tables complement the information provided by the figures illustrating the co-inventorship space.

include: market structure (i.e. the presence in the territory of hubs or affiliated of multinationals, the hosting of subsidiaries of research labs, etc.); the extensiveness and quality of the system of technological research incentives in the region; and the overall country characteristics. It is interesting to observe that even for top patenting regions, national borders still play an important role. For most regions, more than half of patent applications co-signed with researchers outside the region are with individuals located in the same country. Especially in Japan and Korea, top patenting hubs tend to have high shares of collaboration with regions located in the same country. This is also true for US states, albeit some global hubs such as California or Massachusetts are more open towards other continents than "average" US patenting hubs. German regions and Ile-de-France show, generally, a balanced openness to co-inventors within and outside the country. Other highly patent-intensive EU regions (especially small regions in Nordic countries) tend to be more connected with foreign EU (or even non EU) regions, than with regions found in their national borders. Again, this is clearly caused by a size effect that pushes researchers in smaller countries to collaborate internationally, as already observed for the case of Western Netherlands in the renewable energy field. Two regions deserve particular attention. Ontario has the highest share of collaborations outside Canada and within the continent (namely with the US). Guangdong has the highest share of collaboration globally (namely outside of China and even Asia). (See Tables 5, and Tables 7, 8 in Annex II for details).

Table 5. The geography of connectivity: biotechnology

Regional share (%) 2005-2007

Biotechnology	Within country	Within continent	Other
US42 Pennsylvania	85.68	1.60	12.71
JPF Toukai	84.33	2.90	12.77
US48 Texas	80.45	2.51	17.04
US34 New Jersey	80.29	0.84	18.88
US36 New York	79.76	1.39	18.84
KR01 Capital Region	78.35	4.90	16.75
US24 Maryland	77.11	1.66	21.23
US17 Illinois	76.26	4.08	19.66
US53 Washington	75.85	5.08	19.07
US37 North Carolina	69.11	2.12	28.76
JPC Southern-Kanto	68.78	4.26	26.96
US06 California	67.91	3.22	28.87
US25 Massachusetts	63.24	2.80	33.96
DEA North Rhine-Westphalia	62.61	23.69	13.71
DE1 Baden-Württemberg	50.74	31.85	17.41
FR01 Ile-de-France	46.40	35.60	18.00
DE2 Bavaria	40.68	48.98	10.34
NL3 Western Netherlands	39.92	41.07	19.00
DK01 Capital Region	26.82	44.70	28.48
CA35 Ontario	19.58	43.37	37.05

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

5. REGIONAL CO-INVENTORSHIP NETWORKS: STRUCTURE AND EVOLUTION OVER TIME

Network analysis allows us to study the evolution of regional co-inventorship networks over time. The network is observed for the biotech sector since 1984 and for telecommunication from 1990 onwards. Before those periods, the networks were too sparse (almost not existent) to be analysed. In the case of renewable energy, it has not been possible to study the evolution, but only the configuration of the network in the most recent period, due to the low numbers of patents applied for in that sector.[19]

As the co-patenting grows in intensity, networks become denser in terms of connections and more regionally dispersed (i.e. increasing number of regions participating in the network). From the 1980s through the mid 2000s, the number of connected regions increased from 68 to 215 in telecommunications and from 56 to 215 in biotechnologies.

The trend in the number of links is different with respect to technological sectors. Links increased by more than 14-fold, when considering all patent applications in every sector, but only by 8-fold in the telecommunication sector. The case of biotechnology is peculiar, since the total number of links increased 12-fold from 1984 to 1999-2001 and then declined slightly (from 1 380 to 1 226 links) from 1999 to 2007, in line with the patent boom of the sector in the 1990s. The average number of spatial connections per region (average degree) roughly tripled for both the biotech and the telecom sector, stabilising around 2000, (see Tables 9, 10, 11, 12 in Annex II).

The networks differ in their structure according to the technological field. The average clustering coefficient[20] (i.e. the propensity of the network to be structured in densely connected sub-networks) decreases in the telecommunication network, but has no clear trend over time in biotechnology. This may suggest that in telecommunications, regions are less densely clustered, and, therefore, the network is more centralised, meaning formed by several global or local star-type hubs, that act as collectors of links. In biotechnology, the clustering coefficient has been stable over time. Hence the biotechnology networks do not show an increasing polarisation by few actors over time. This is confirmed by the trend in the betweenness centralisation.[21] This indicator decreases over time in biotechnology, while it has been stable (slightly increasing) in telecommunications. Hence, in biotechnology the network tends to be constituted, to a greater extent over time, by multi-hub/polycentric collaboration sub-networks, in contrast to the co-inventorship network in telecommunications that appears more oriented towards a global star hub-type structure, mainly dominated by the role of California. These findings are consistent with what is observed in the co-inventorship spaces of top 20 patenting hubs in different technologies, described in the previous section, where differences in co-inventorship models are more pronounced in the telecommunications than in the biotechnology field.

Regional patenting networks tend to be scale free.[22] Even though first movers tend to maintain their technological advantage (preferential attachment of nodes), there are opportunities for new actors to join the network. The degree distribution of the co-inventorship networks in each technological field follows (approximately and with a great deal of noise) a power law that is clearly distinct from the typical bell shaped distribution, characterising random networks (Barabasi and Albert, 1999) (See Figures 15 and 16 in

[19] Since patenting is a volatile phenomenon, 3-year periods were considered. Regions applying for fewer than 3 patents or 3 inter-regional co-patents were excluded from the analysis. The goal was to include in the study regions with a minimum of patenting activity.

[20] For the detailed definitions of the social network analysis indicators mentioned in this section, see Annex I.

[21]See note 20.

[22] See Annex I for the definition of scale free networks.

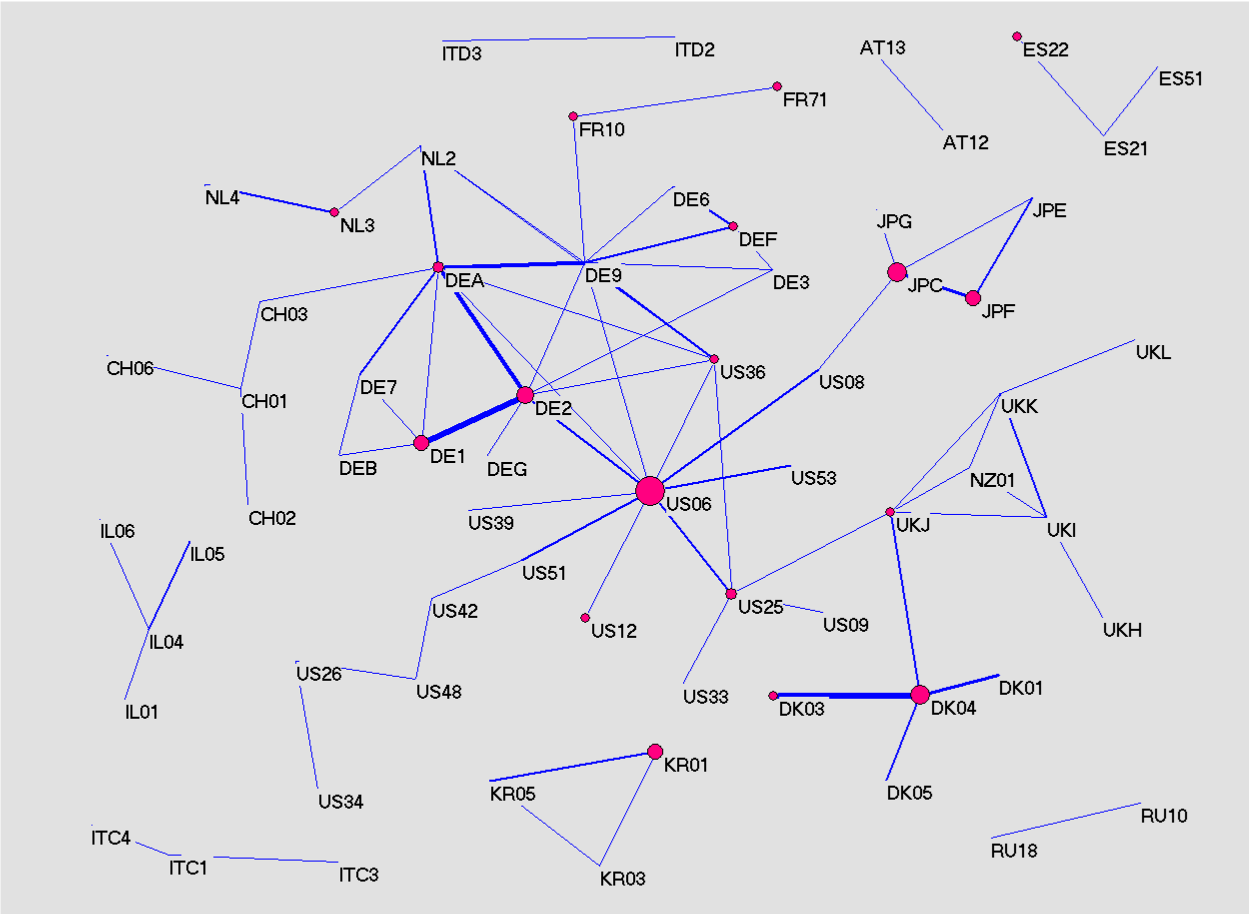
Annex II)[23]. This means that there are a limited number of regions with a large number of connections that are key-players in the global network structure. A very small number of actors are of extreme importance for the co-inventorship-connectivity phenomenon; one out of 200 in the case of the telecommunication network, for example. The absolute value of the power law exponent is also decreasing over time (except for the biotech sector where there is mixed evidence).This is in part due to the fact that first movers often maintain their technological advantage (preferential attachment) in building and choosing connections to other regions. An additional explanation is that, since new players are joining the game, with a subsequent increase in link creation over time, they move forward in the degree distribution, making the "fat tails" even fatter.

In renewable energy patenting, it is possible to display the full network for the period 2005-2007, given the early stage of technological development (see Figure 8).[24] Each node is a region with a least three co-invented patents, with an inventor located in another region. The size of the nodes corresponds to the share of regional patenting over total patenting in renewable energy for the top 20 patenting regions, while the intensity of the link measures the number of co-patents between the two nodes. California (US06) is connected to other regions (US states or German regions) by means of a star-type collaboration model, while German hubs such as North Rhine-Westphalia (DEA), Bavaria (DE2), and Baden-Württemberg (DE1) show a more multi-hub oriented behaviour. A peculiarity of this network is the existence of a dense network of cross-country regional collaborations, which is partly the result of the increasing globalisation of science and technology over time; in fact, both telecommunications and biotechnology co-patenting networks displayed a lower degree of internationalisation in their earlier stages of development. Other significant players in the network are Central Denmark (DK04), a star connected to other peripheral Danish or UK regions, Southern Kanto (JPC) and Toukai (JPF), a double hub linked to other US or Japanese regions, and Korea Capital Region (KR01) linked to other Korean regions as an isolated sub-network.

[23] A power law is a distribution characterised by the so-called "fat tail phenomenon", namely the decay of the tail of the distribution is less rapid than the one of the exponential distribution. In other words, the tail effect is not negligible and must be taken into account. See Annex I for details.

[24] Given the high number of linkages among regions in the biotech and telecom sectors, the networks cannot be displayed and their topology is analysed by means of indicators. Parts of these networks are illustrated in Annex II.

Figure 8. Regional co-inventorship network: renewable energy 2005-2007



Note: The size of nodes correspond to the share of regional patenting over total patenting in renewable energy.

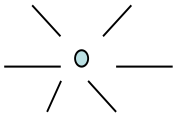
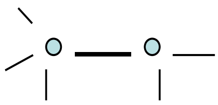
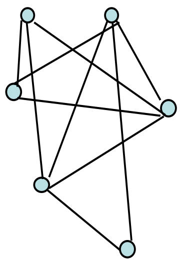
List of regions in the network – AT12- Lower Austria, AT13- Vienna, CH01- Lake Geneva Region, CH02- Espace Mittelland, CH03- Northwestern Switzerland, CH06- Central Switzerland, DEA- North Rhine-Westphalia, DEB- Rhineland-Palatinate, DEF- Schleswig-Holstein, DEG- Thuringia, DE1- Baden-Württemberg, DE2- Bavaria, DE3- Berlin, DE6- Hamburg, DE7- Hessen, DE9- Lower Saxony, DK01-Denmark Capital Region, DK03- Southern Denmark, DK04-Central Denmark, DK05- North Denmark, ES21- Basque Country, ES22- Navarra, ES51- Catalonia, FR10-Ile-de-France, FR71- Rhône-Alpes, IL01- Jerusalem, IL04- Central Israel, IL05- Tel Aviv, IL06- Southern Israel, ITC1- Piedmont, ITC3- Liguria, ITC4- Lombardy, ITD2- Province of Trento, ITD3- Veneto, JPC- Southern-Kanto, JPE- Hokuriku, JPF- Toukai, JPG-Kansai, KR01-Capital Region Korea, KR03- Gyeonbuk, KR05- Chungcheong, NL2- Eastern Netherlands, NL3- Western Netherlands, NL4- Southern Netherlands, NZ01- North Island, RU10- Moscow Oblast, RU18- City Of Moscow, UKH- Eastern, UKI- London, UKJ- South East, UKK- South West, UKL- Wales, US06-California, US08- Colorado, US09- Connecticut, US12-Florida, US25- Massachusetts, US26- Michigan, US33- New Hampshire, US34- New Jersey, US36- New York, US39- Ohio, US42- Pennsylvania, US48- Texas, US51- Virginia, US53- Washington

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

To summarise the different forms of connections of top patenting regions, Table 6 presents a taxonomy of variety in network topology (structures of connections between nodes) and regional openness (variety in extra-regional partners) for top patenting regions in the three technological fields. The table provides examples of collaboration modes in 2005-2007 and highlights country and regional effects in defining collaboration models (see Figures 12, 13, 14 in Annex II for graphical representations of sub-networks).

Table 6. Variety in the structure of regional networks: country and sectoral patterns

2005-2007

Network topology	REGIONAL OPENESS		
	LOW	MEDIUM	HIGH
STAR 		Bavaria California	California California Massachusetts
STAR + SATELLITE	Ile-de-France & Rhône Alpes	Ile-de-France & Brittany	
DOUBLE- HUB 	Korea Capital Region & Chungcheong Southern Kanto & Toukai Southern Kanto & Toukai	Denmark Capital Region & Central Denmark Southern & Western Finland Stockholm & East-Middle Sweden Korea Capital Region & Chungcheong	
MONO-HUB with INTERNATIONAL GATEKEEPER	Guandong & Beijing		
MULTI-HUB 	Southern, Eastern & Western Netherlands	California, Massachusetts, Maryland, New York, North Carolina, Pennsylvania, New Jersey, Illinois, Washington, Texas & Ontario Baden-Württemberg, Bavaria & North Rhine-Westphalia California, New Jersey, Texas, New York, Massachusetts, North Carolina, Illinois, Washington & Ontario Bavaria, Berlin, Hesse, North Rhine-Westphalia & Baden-Württemberg Bavaria, North Rhine-Westphalia & Berlin California, New York & Massachusetts	

TECHNOLOGICAL SPECIALIZATION	BIOTECHNOLOGY	RENEWABLE ENERGY	TELECOM

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

The analysis of the configuration and evolution of co-inventorship networks over time shows that patenting is a very concentrated phenomenon, where early movers have a good probability of maintaining their leadership, even though leadership is not acquired once for all. There are windows of opportunity for newcomers to enter the network and to transform the global structure into a multi-hub type with several key global players, such as in the biotechnology field, for example. Becoming a new hub in a pre-existing network is possible, but it is hard due to preferential attachment properties and to path-dependency in the evolution of the network. Clearly networks are open and it is possible for new actors to participate in the network once they have the critical mass of capabilities for doing so. Evidence supports that the role of spatial proximity and capability proximity is mixed in influencing co-inventorship patterns. In fact, excellence networks include star players regardless of the proximity; but several well-performing actors benefit from proximity or relative proximity of agents.

6. CONCLUDING REMARKS

There is wide acknowledgement that networks are increasingly important for innovation. Less is known about the characteristics of networks for innovation, the role of regions and territorial location in shaping collaboration patterns and the variety of collaboration behaviours that co-exist in global economies. This paper marks one of the first steps in an exploration of these issues, on the basis of data on collaboration in innovation through co-patenting among OECD and selected non-OECD regions. It provides an overview of co-inventorship patterns at the regional level, focusing on the performance of top patenting regions, by combining descriptive statistics with social network analysis. Clearly, there is more work to be done in understanding how and to what extent the different "shapes of the innovation networks" identified might affect the pace of innovation and/or diffusion of new products and technologies. Nevertheless, even this preliminary analysis points to a number of conclusions:

- **Top patenting regions exhibit very different collaborative behaviours:** some tend to reach a great number of extra-regional partners, whereas others tend to co-invent in a less "open" fashion. In other words, there is no linear relationship between propensity to collaborate and technological leadership. Various collaboration patterns co-exist among global patenting hubs, from more to less "open" behaviours, exemplified by the cases of California and Guangdong in telecommunications, among others. Such patterns are linked to country-effects, industry and market structure, and also to different phases in the evolution of the industry (leadership versus catching-up).

- Co-inventorship **networks evolve over time and tend to become denser**, with a rising share of extra-regional collaborations over time. Collaboration between early co-inventors tend to be reinforced, while new actors enter in the network by connecting to inventors located in regions with accumulated capacities in the technological field in question.

- Co-inventorship **networks in different technologies show different evolution patterns** over time. The biotech network is evolving towards a polycentric-multi-hub structure, whereas the telecommunications network tends to become, to a greater extent, a mono-hub-star over time.

- First movers, i.e. **early leaders, tend to maintain their leadership role over time, but there are windows of opportunity for other localities** to become local, national or global hubs. This catching-up is often the result of two factors combined: public policy action and effective market development (as in the case of German regions in the biotechnology field or Navarra in the renewable energy sector).

- **Even for top patenting regions, national borders still play an important role:** most top patenting regions, in each of the three technologies selected, show a high propensity to establish co-patenting collaborations within their national borders. This is likely to happen for several concurring reasons, like the geographical proximity or relative proximity of agents as well as the possible scientific, linguistic and cultural distance from researchers abroad, that make collaborations more difficult. There are, however, some exceptions. Some top patenting hubs have a high propensity to co-patent with inventors located in foreign countries: this is generally the case of small regions in innovation-intensive countries (as regions in Nordic Europe) that often need to reach markets abroad, due to the lack of critical mass within their national borders.

The analysis presented here is too preliminary and aggregate to form a basis for detailed policy recommendations. However, it does suggest two general conclusions of relevance for policy-makers:

- "Technology-based" advantages are created over time beyond current endowments and strengths, so "transformation strategies" matter. Regional and national governments should pay attention to identify the right mix of policies to foster the creation of new competences in emerging fields Windows of opportunity open, but it is not easy nor automatic to take advantage of them, and they can close relatively quickly as other players occupy strong positions in new activities;

- Fostering collaboration and networking is relevant to all, but it is more important for some agents, industries and regions than for others. Agents differ in their propensity to collaborate according to sector, stage of development and prevailing market structure. At the same time, there is no optimal collaboration strategy. Local and global collaborations might both affect positively innovation processes, depending on several issues. Therefore, it is important to manage the policy mix carefully to encourage collaborations depending on the specificities of different ecosystems.

As innovation grows in importance as a source of economic growth and competitiveness, and as it changes its nature, the innovation measurement agenda needs to be strengthened. Social network analysis, as shown in this paper, illustrates the value of experimenting with new tools for a better understanding of the multidimensionality and the variety of behaviours associated with innovation. This paper provides a general overview of co-inventorship, by taking regions as units of analysis. However, in order to explore the phenomenon of connectivity and collaboration further, several directions of research can be taken:

- Analyses at a further micro-scale to better understand co-inventorship collaboration, by taking firms and other patenting-intensive actors as the unit of analysis. This will help reveal which kind of partnerships generate the aggregate regional behaviour described in this paper and which particular actors play the role of connectors (namely private or public institutions, multinationals, etc.).

- Expanding the focus to go beyond co-patenting to include other forms of collaboration activities such as co-authorship in academic papers or joint participation in research projects. The analysis and the comparison of these networks can certainly provide additional information on the connectivity of different regional innovation systems.

- Quantitative/econometric studies with the aim to understand the linkages, if any, between the different forms of connectivity in innovation-related phenomena and the economic performance of regions.

Further studies in these directions can improve our understanding of innovation phenomena, in order to deliver better policies by fostering a multi-dimensional approach that puts back the territory and innovation systems as relevant spaces for policy action.

ANNEX I

Network analysis: some notes and definitions. A network is a set of interconnected elements, where each connection represents a proven link among identified actors. The interconnected elements are called the nodes of the network and connections are called links or arcs.

Social networks are a simple and flexible tool that may be applied to all phenomena involving multiple interacting actors. These flexibilities and simplicity properties have made social networks one of the widely used theoretical frameworks able to suitably model socio-economic phenomena.

Some definitions and properties that help in analysing the network structure follow:

- The **degree** of a node - The degree *k* of a node *i* in a network is the number of links which connect node *i* to other nodes (the larger the degree the more "important" is a node, in our case the degree represents the total number of inter-regional connections a region has). The average degree is the average computed on all nodes of the network.

- The **degree distribution** of the network –The degree distribution of a network *P(k)* is defined as the fraction of nodes in the network with degree *k.* Given the total number of nodes *n* in the network, if n_k of them have degree *k*, then $P(k)= n_k /n$. (P(k) may be seen as the probability that a randomly selected node has exactly k links*)*.

- A **cluster** of nodes is a group of nodes highly connected to one another.

- A **fully connected clique** is a subset of a network where every node is linked to every other node.

- The **clustering coefficient** of the network measures the propensity of the network to create clusters. - The clustering coefficient, C, can be formally defined as follows: for any node i one picks the k_i nodes linked to node i. If these nodes are all connected to one another, for example, (i.e. they form a fully connected clique), there will be $k_i(k_i -1)/2$ links between them. Denoting with K_i the actual number of links that connect the selected k_i nodes to each other, the clustering coefficient for node i is then defined as $C_i = 2K_i/k_i (k_i -1)$. The clustering coefficient for the whole network is obtained by averaging C_i over all nodes in the system. It tells us to what extent a node is within a highly connected cluster of nodes.[25]

- The **betweenness centrality** of a node is the proportion of all geodesics (shortest paths) between pairs of other nodes that include this node. It is a measure of how central is a node in the global structure of the network.

- The **betweenness centralisation** is the variation in the betweenness centrality of vertices divided by the maximum variation in betweenness centrality scores possible in a network of the same size.

[25] A weighted version of the clustering coefficient has been used in this paper to analyse co-patenting networks. The definition is the following: $C'_i= C_i * (deg(i)/MaxDeg)$, where deg(i) is the degree of node i and MaxDeg the maximum degree of nodes in the network.

When the degree distribution of the network appears to be a polynomial relationship that exhibits the property of scale invariance, namely a **power law**, the network is said to be *scale-free*. The property of scale invariance is shown in the formula below: if the independent variable *x* is multiplied (namely scaled) by a constant factor, the shape of the function does not change. This explains the term *scale-free.* It follows that all power laws with a particular scaling exponent are equivalent up to constant factors, since each is simply a scaled version of the others. Technically speaking, the most common power laws relate two variables and have the form:

$$f(x)= a\, x^{k}$$

$$f(cx)= a\, c^{k}\, x^{k} \sim f(x) \quad \text{and}$$

$$\log (f(x)) = k \log (x) + \log (a) \text{, where c is constant.}$$

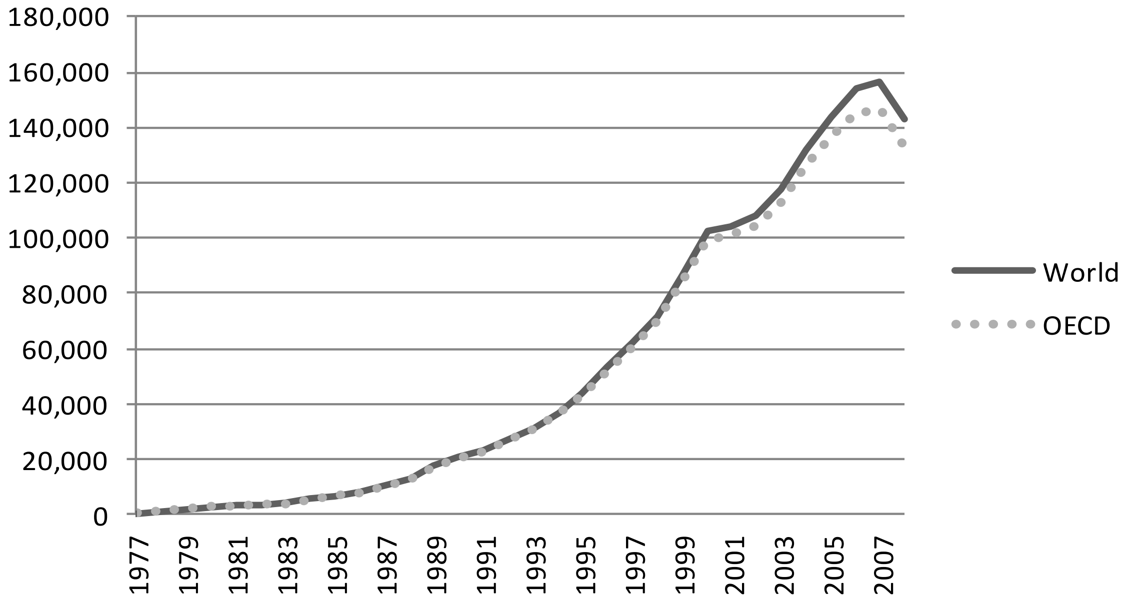
A power law is therefore a special kind of mathematical relationship between two quantities. If one quantity is the frequency of an event, and the other the size of the event, then the relationship has a power-law distribution when the frequency of the event decreases at a greater rate than the size increases. The distribution of a wide variety of natural phenomena follows a power law.

ANNEX II

ADDITIONAL TABLES AND FIGURES

Figure 9. Number of PCT patent applications

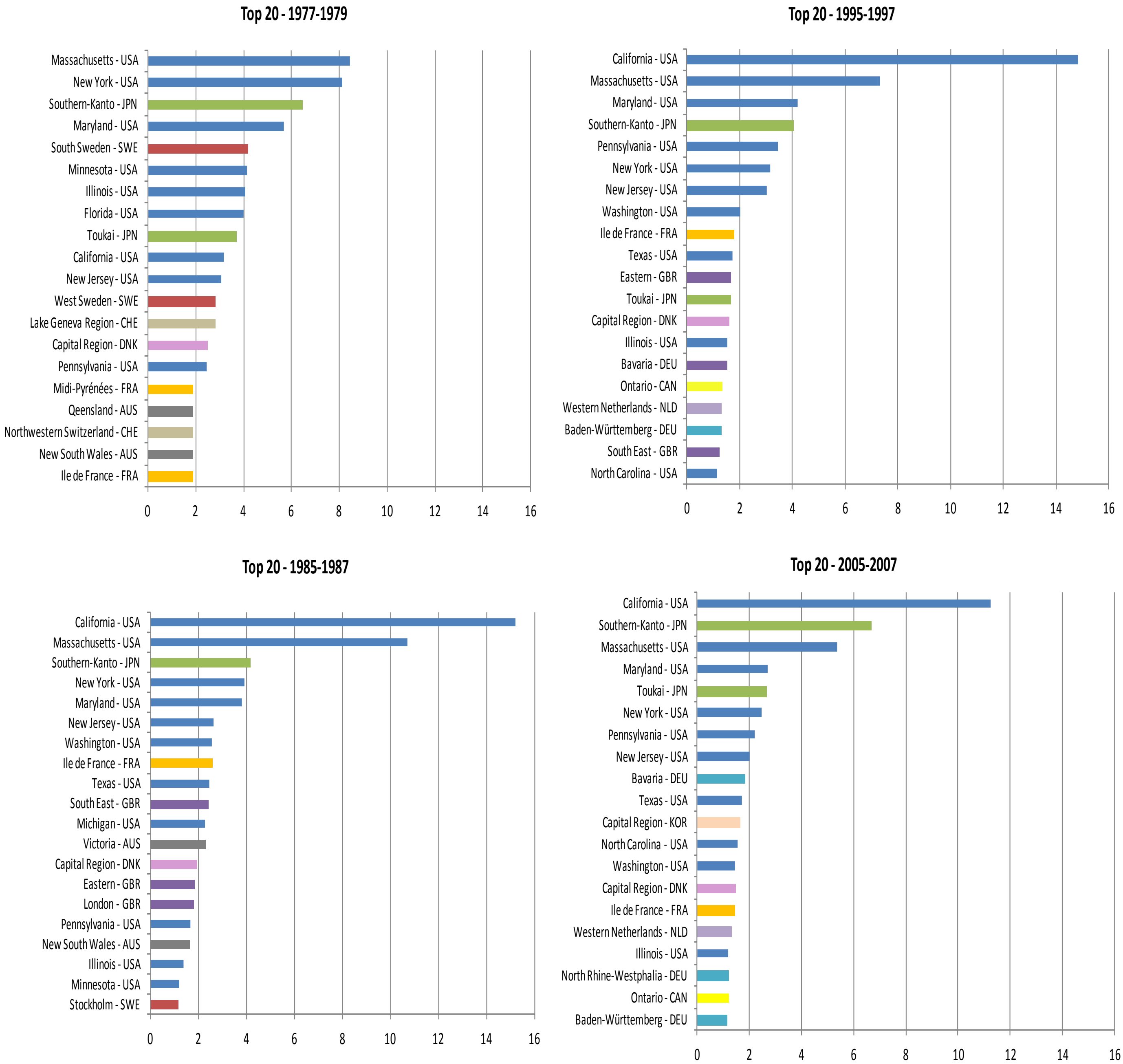
1997-2007



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 10. Top 20 patenting regions in biotechnology

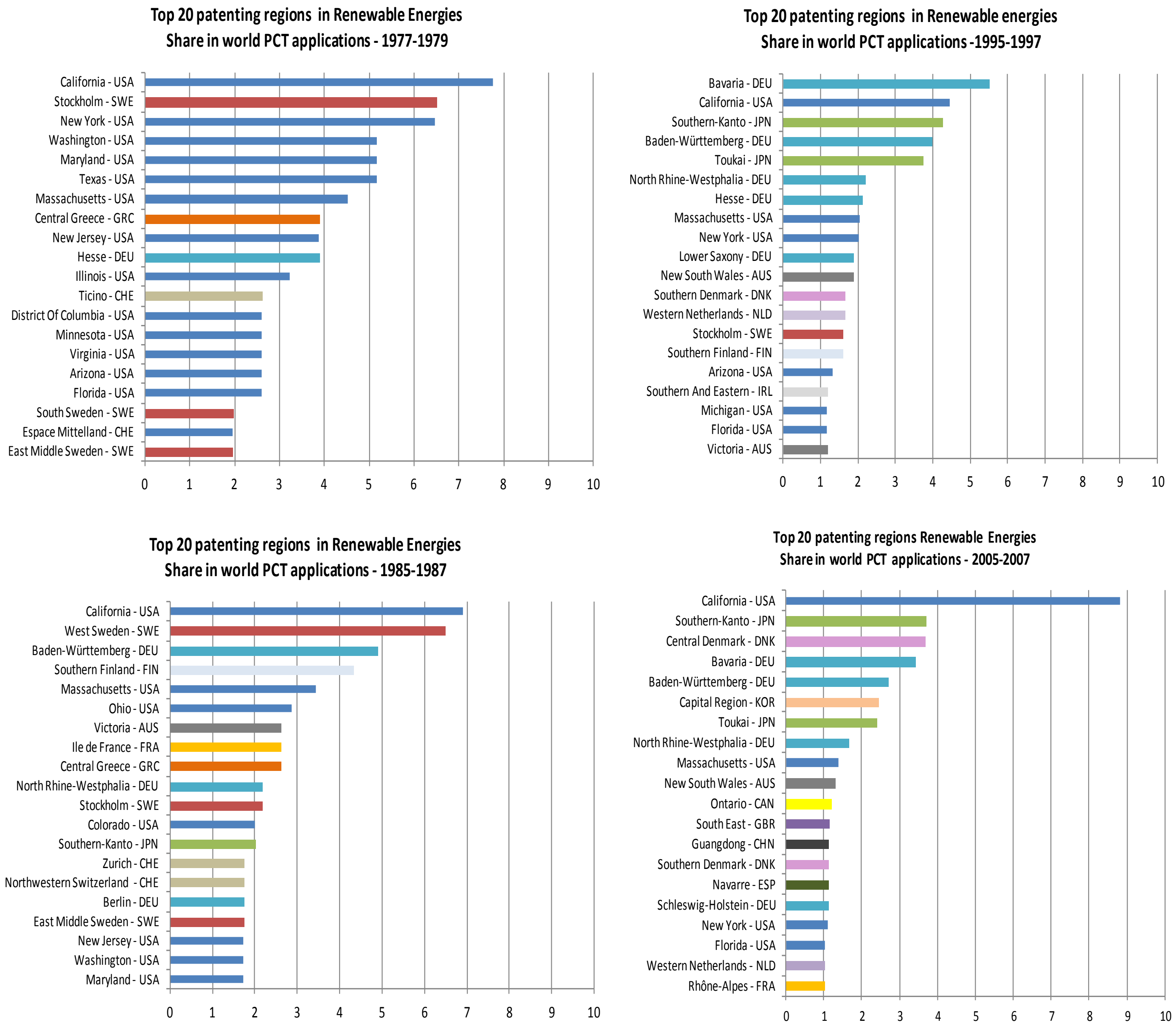
Regional share over total PCT applications (in %)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 11. Top 20 patenting regions in renewable energy

Regional share over total PCT applications (in %)



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 7. The geography of connectivity: telecommunications

Regional share 2005-2007 (in %)

Telecommunications	Within country	Within continent	Other
KR05 Chungcheong	96.85	0.84	2.31
US34 New Jersey	79.59	2.23	18.17
US25 Massachusetts	78.87	1.94	19.19
US53 Washington	76.24	3.55	20.21
US36 New York	72.34	11.81	15.86
US17 Illinois	68.78	2.34	28.89
JPF Toukai	64.62	5.13	30.26
US06 California	64.41	4.98	30.61
US48 Texas	61.94	5.54	32.52
US37 North Carolina	61.72	5.02	33.26
DE1 Baden-Württemberg	61.38	22.76	15.87
KR01 Capital Region	60.00	9.56	30.44
FR10 Ile-de-France	59.61	19.22	21.17
DE2 Bavaria	54.53	31.63	13.84
FI18 Southern Finland	40.03	39.88	20.09
SE11 Stockholm	39.89	40.03	20.08
NL4 Southern Netherlands	38.85	45.32	15.83
JPC Southern-Kanto	38.19	4.31	57.49
CA35 Ontario	28.88	49.23	21.88
CN19 Guangdong	26.45	2.48	71.07

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 8. The geography of connectivity: renewable energy

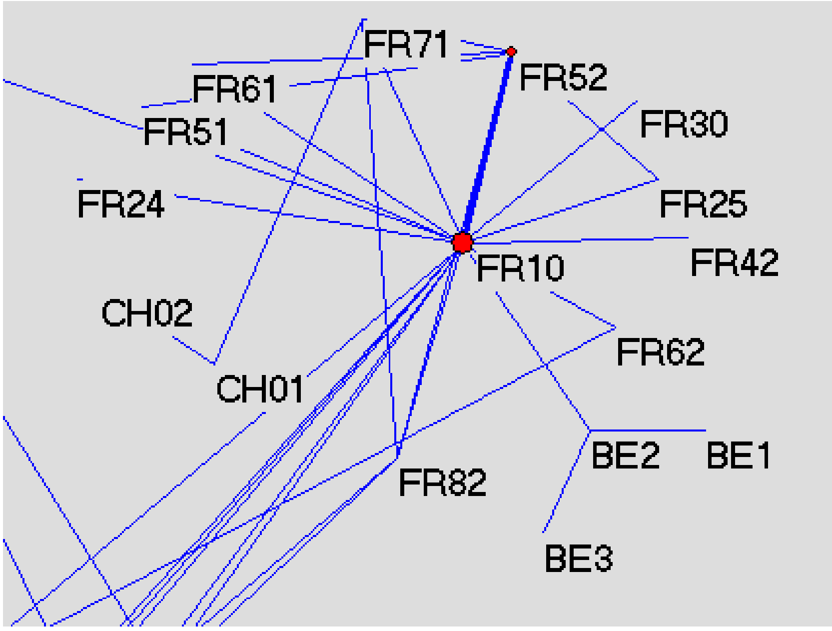
Regional share 2005-2007 (in %)

Renewable energy	Within country	Within continent	Other
JPF Toukai	100.00	0.00	0.00
DEF Schleswig-Holstein	95.83	4.17	0.00
KR01 Capital Region	92.31	0.00	7.69
DK03 Southern Denmark	80.65	19.35	0.00
US12 Florida	80.00	0.00	20.00
US25 Massachusetts	76.92	0.00	23.08
DE1 Baden-Württemberg	74.00	18.00	8.00
DK04 Central Denmark	69.81	28.30	1.89
JPC Southern-Kanto	66.67	0.00	33.33
DE2 Bavaria	62.34	22.08	15.58
US06 California	62.07	0.00	37.93
UKJ South East	60.00	15.00	25.00
FR71 Rhône-Alpes	58.33	8.33	33.33
DEA North Rhine-Westphalia	55.13	23.08	21.79
NL3 Western Netherlands	53.33	33.33	13.33
US36 New York	51.06	0.00	48.94
CN19 Guangdong	50.00	0.00	50.00
AU1 New South Wales	44.44	0.00	55.56
ES22 Navarra	43.75	31.25	25.00
CA35 Ontario	16.67	50.00	33.33

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 12. Star with Satellite

Ile-de-France and Brittany: Telecommunications, 2005-2007

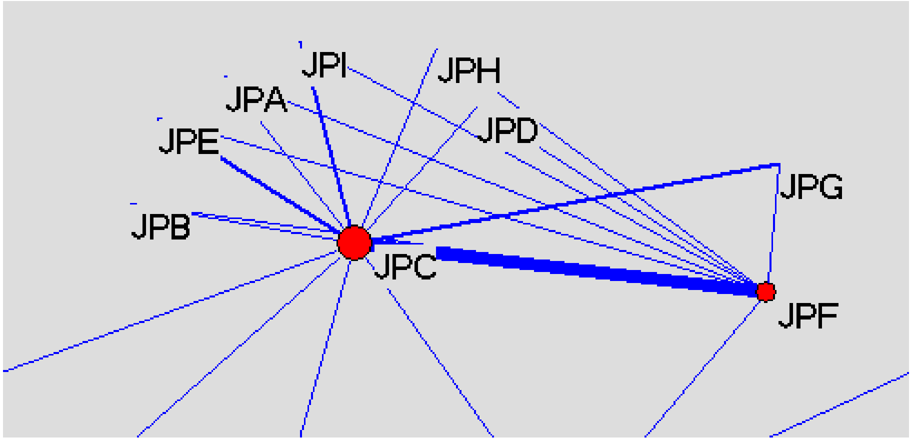


Note: FR10-Ile-de-France, FR52- Brittany, FR71- Rhône-Alpes, FR61- Aquitaine, FR51- Pays de la Loire, FR24- Centre, FR30- Nord-Pas-de-Calais, FR25- Lower Normandy, FR42- Alsace, FR62- Midi-Pyrénées, FR82- Provence-Alpes-Côte d'Azur, BE2-Flanders, BE3-Wallonia, BE1-Bruxelles Capital Region, CH02- Espace Mittelland, CH01- Lake Geneva Region

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 13. Double hub

Southern Kanto and Toukai (Japan): Biotechnology, 2005-2007

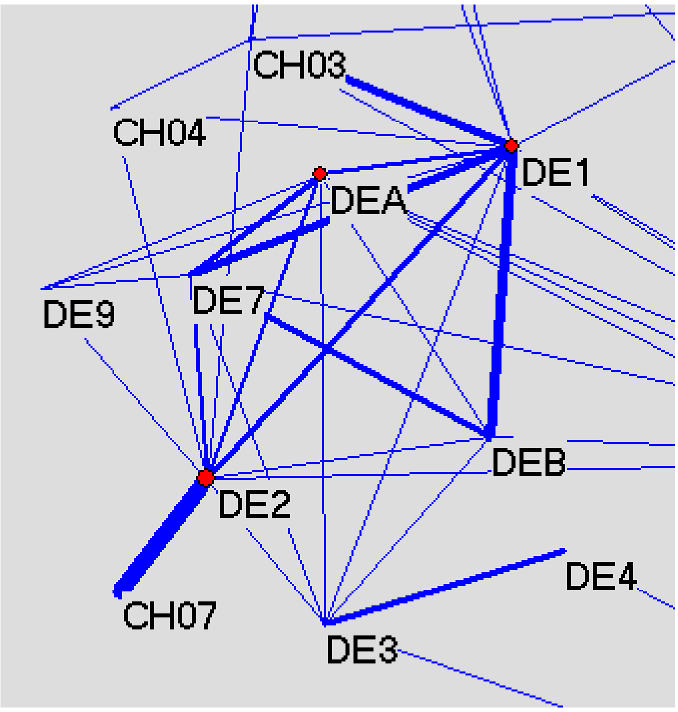


Note: JPC-Southern-Kanto, JPF-Toukai, JPB-Tohoku, JPE-Hokuriku, JPA-Hokkaido, JPI-Shikoku, JPH- Chugoku, JPD- Northern-Kanto/Koshin, JPG-Kansai.

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 14. Multi-hub

German/Swiss regions: Biotechnology, 2005-2007

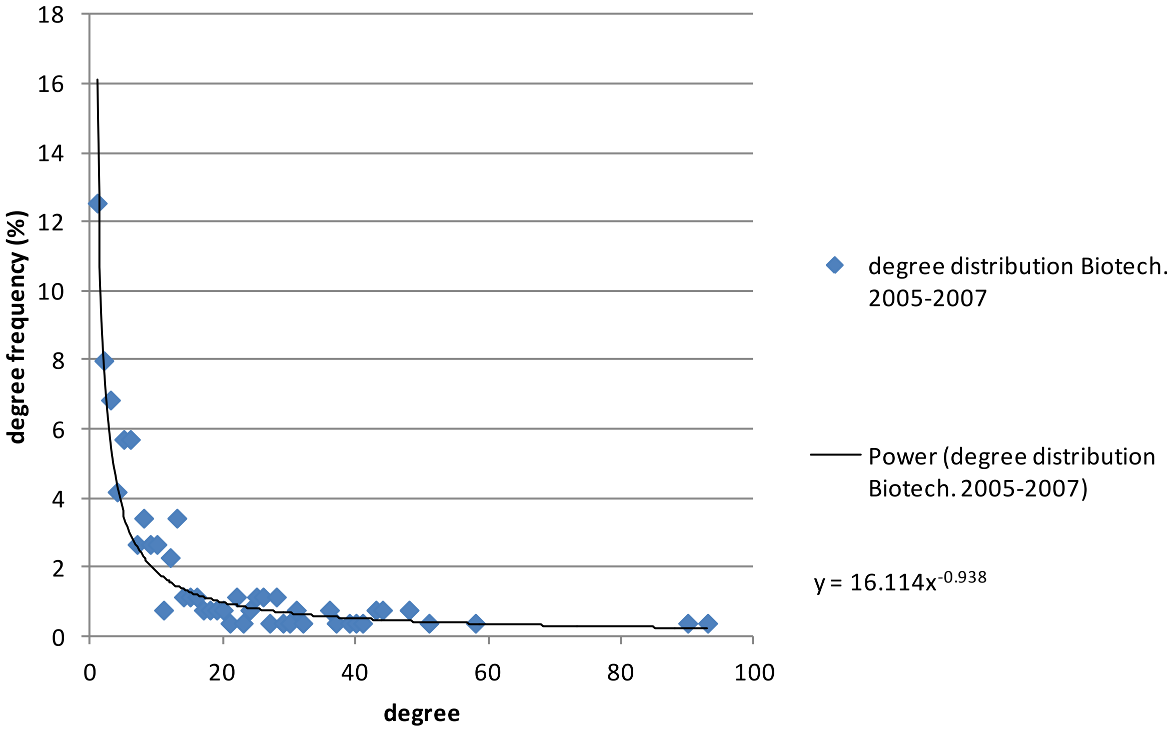


Note: DE1- Baden-Württemberg, DEA- North Rhine-Westphalia, DE7- Hesse, DE2- Bavaria, DEB- Rhineland-Palatinate, DE3- Berlin, DE4- Brandenburg, DE9- Lower Saxony, CH07- Ticino, CH04- Zurich, CH03- Northwestern Switzerland

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

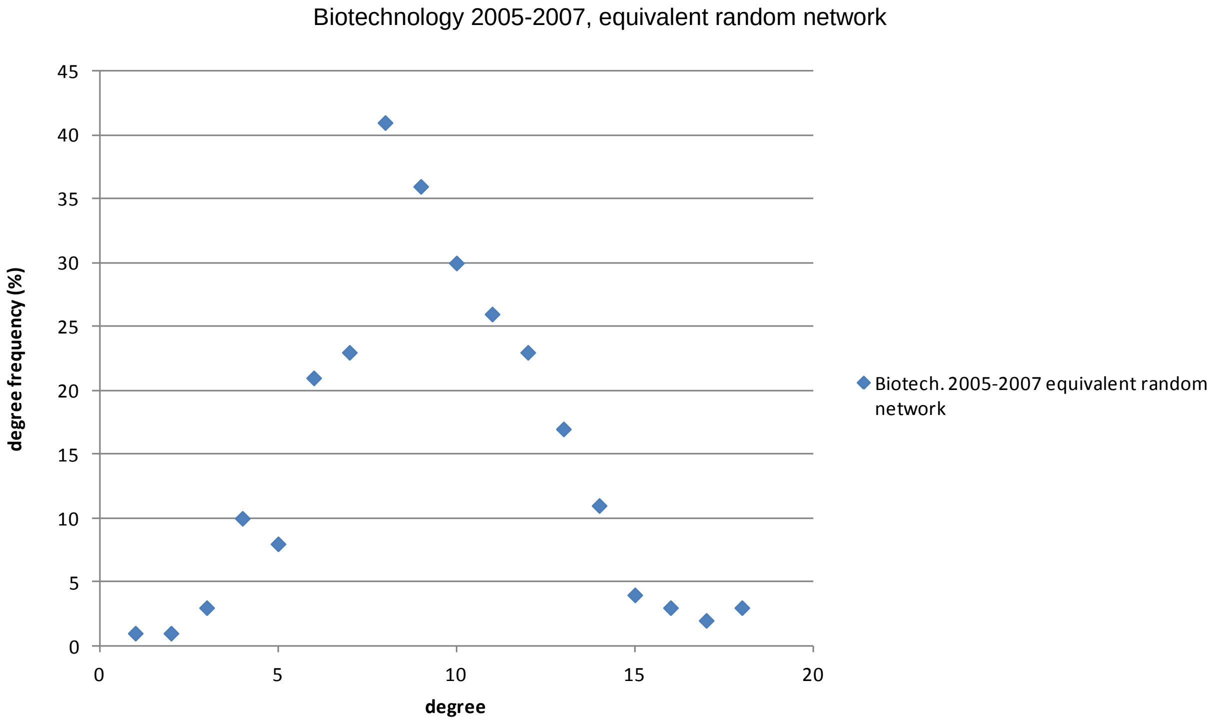
Figure 15. Degree distribution: Power law shape

Co-inventorship network: Biotechnology, 2005-2007



Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Figure 16. Degree distribution. Bell shape



Note: Erdős-Renyi (Erdős and Renyi, 1950) random network with equivalent average degree.

Table 9. Network indicators over time: total PCT applications

Total Patents	Number of regions	Links	Average Degree	Average Clustering Coeff.	Betweenness Centralisation
1978-1980	129	440	6.82	0.0960	0.1880
1981-1983	155	706	9.11	0.0801	0.2018
1984-1986	186	1066	11.46	0.0863	0.1628
1987-1989	207	1630	15.75	0.0876	0.1677
1990-1992	229	2013	17.58	0.0797	0.1736
1993-1995	259	2644	20.42	0.0781	0.1577
1996-1998	295	3720	25.22	0.0803	0.1554
1999-2001	360	4920	27.33	0.0778	0.1165
2002-2004	379	5692	30.04	0.0803	0.1117
2005-2007	400	6340	31.70	0.0765	0.1283

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 10. Network indicators over time: telecommunications

Telecom	Number of regions	Links	Average Degree	Average Clustering Coeff.	Betweenness Centralisation
1990-1992	68	120	3.53	0.0654	0.2755
1993-1995	102	228	4.47	0.0509	0.3460
1996-1998	129	441	6.84	0.0529	0.3352
1999-2001	178	732	8.22	0.0434	0.3691
2002-2004	188	880	9.36	0.0427	0.3500
2005-2007	215	999	9.29	0.0402	0.3265

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 11. Network indicators over time: biotechnology

Biotech	Number of regions	Links	Average Degree	Average Clustering Coeff.	Betweenness Centralisation
1984-1986	56	117	4.18	0.0762	0.4312
1987-1989	103	295	5.73	0.0519	0.3790
1990-1992	125	474	7.58	0.0538	0.3518
1993-1995	153	619	8.09	0.0440	0.4229
1996-1998	178	980	11.01	0.0516	0.3243
1999-2001	210	1380	13.14	0.0538	0.3032
2002-2004	220	1299	11.81	0.0509	0.2742
2005-2007	215	1226	11.40	0.0561	0.2029

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 12. Network indicators over time: renewable energy

Renewable energy	Number of regions	Links	Average Degree	Average Clustering Coeff.	Betweenness Centralisation
2005-2007	66	78	2.36	0.0714	0.2627

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

Table 13. Power law exponents over time, by technology

	All patents	Biotech	Telecom	Renewable energy
1978-1980	-1.025			
1981-1983	-0.952			
1984-1986	-0.951	-1.001		
1987-1989	-0.827	-0.984		
1990-1992	-0.796	-0.897	-1.206	
1993-1995	-0.790	-0.913	-1.145	
1996-1998	-0.746	-0.883	-1.007	
1999-2001	-0.769	-0.893	-1.022	
2002-2004	-0.724	-0.937	-0.967	
2005-2007	-0.702	-0.938	-0.980	-1.726

Source: Authors' elaboration on the basis of the OECD Regional Patent Database.

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