SPECIAL SECTION

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IDENTIFYING AND RANKING THE WORLD'S LARGEST SCIENCE AND TECHNOLOGY CLUSTERS

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For the first time, the 2017 edition of the Global Innovation Index (GII) presented a ranking of the world's largest clusters of inventive activity.[1] Last year's effort was motivated by the recognition that innovation activities tend to geographically concentrate in specific clusters. Adopting this cluster perspective opens the door to better understanding the determinants of innovation performance that operate at the sub-national level.

The 2017 ranking offered insights on the spatial agglomeration of innovative activity, relying on a globally harmonized set of criteria. It was based on the geocoded addresses of inventors listed in patent filings under WIPO's Patent Cooperation Treaty (PCT). It then measured the size of the identified clusters by the number of PCT applications associated with the inventors present in a given cluster.

As acknowledged in GII's special section last year, patent data are an imperfect metric for inventive activity and an even less perfect metric for innovation activity more broadly. For this year's ranking, we took the first step towards widening the range of innovation metrics included in our research. In particular, we used the data on scientific publications compiled by Clarivate to enlarge the geospatial dataset we use and thus identify and measure broader science and technology clusters.

This chapter reports the results of our enriched analysis. We first briefly describe the scientific publication data and explain how we geocoded our data. We then discuss how we applied the DBSCAN algorithm and measured the size of clusters. We finally present this year's top 100 clusters and discuss key features of those clusters, and end with a few concluding remarks.

For additional background on the patent data we use and the choice of clustering methodology, we refer interested readers to the Special Section on Clusters published in last year's GII report.

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Table 1: Summary of geocoding results

Country	Scientific publications: Number of addresses	Scientific publications: City-level address accuracy (%)	PCT applications: Number of addresses	PCT applications: Block-level address accuracy (%)	PCT applications: Sub-City-level address accuracy (%)	PCT applications: City-level address accuracy (%)	PCT applications: Total address accuracy (%)
United States of America	5,339,705	98.18	803,058	94.61	4.94	0.19	99.73
China	2,444,482	99.10	305,311	2.32	0.27	96.81	99.40
Japan	1,046,116	96.20	505,270	39.22	31.79	27.91	98.91
Germany	1,144,157	97.32	254,843	97.37	0.46	1.58	99.41
United Kingdom	1,135,996	96.53	75,484	78.83	5.59	12.81	97.22
France	977,704	92.78	103,013	85.16	1.35	7.10	93.62
Italy	883,205	95.48	39,345	85.86	4.76	7.67	98.28
Republic of Korea	661,015	93.10	185,861	0.17	0.76	82.20	83.12
Canada	724,727	98.63	41,091	96.66	2.27	0.60	99.53
Spain	668,199	96.59	26,791	66.58	8.30	23.50	98.39
Australia	641,940	86.27	19,410	92.42	5.10	1.16	98.69
India	526,411	96.18	35,147	32.79	39.18	22.28	94.25
Brazil	499,076	98.77	8,526	77.73	13.02	7.49	98.24
Netherlands	433,044	97.30	48,506	91.01	0.68	7.67	99.36
Turkey	341,875	96.66	9,024	27.26	50.8	17.00	95.06
Switzerland	261,694	90.86	34,227	86.90	6.54	5.30	98.74
Russian Federation	279,909	99.09	15,347	81.02	5.34	11.08	97.44
Sweden	244,009	97.58	37,491	94.45	0.89	3.92	99.26
Poland	238,847	98.84	5,779	95.09	2.54	1.54	99.17
Belgium	206,156	94.10	16,680	92.13	1.18	5.12	98.42

Notes: This list includes the top 20 countries that account for the highest combined shares of patents and scientific articles. PCT inventor addresses were geocoded to highest level of detail. Due to the much larger volume, scientific author addresses were geocoded to the city level only.

Description of scientific publication data

Since its systematic compilation in 1960, bibliographic information contained in scientific articles has been used to measure the scientific performance of individual scholars, academic institutions, and countries as a whole. Indeed, scientific publishing activity is a longstanding variable in the GII.[2]

For several decades, the Science Citation Index (SCI) created by the Institute for Scientific Information was the only comprehensive source of such scientific information.[3] Today there are several databases available on scientific publication activity. The two main ones with global coverage are the Web of Science's SCI Expanded (SCIE), published by Clarivate; and SCOPUS, published by Elsevier.[4]

These databases differ in their coverage of journals and languages. In a nutshell, the SCIE offers better language coverage at the expense of somewhat reduced journal coverage compared to SCOPUS.[5] To promote the international comparability of scientific activity—especially with Asian countries—we opted to use the SCIE. In particular, our analysis is based on scientific articles in the SCIE for the last available five years (2012–16). We limit ourselves to the broad field of science and technology, disregarding scientific articles in the fields of social sciences and humanities.

In total, our SCIE extract includes 8.5 million articles from across 113 scientific fields.

Geocoding addresses of inventors and scientific authors

Our analysis focuses on patents and scientific articles published in the 2012–16 period. In the case of patents, our population consists of approximately 1 million patents filed under the PCT, which list 2.8 million inventors that account for close to 1 million unique addresses. In the case of scientific articles, our population consists of 8.5 million articles, which list 22.5 million authors that account for an additional 7.4 million unique addresses.

We geocoded these addresses as follows. First, we used the ArcGIS service of Esri to geocode inventor addresses for all countries, except China, Japan, and the Republic of Korea. For the latter three countries, the address matches of ArcGIS proved insufficiently accurate. We therefore adopted an alternative approach for these countries whereby we identified the city name in the address string by matching address records with the city-level data from GeoNames' gazetteer database.[6] This latter database also provides the geocodes of each city. Finally, using an equivalent approach, we relied on the GeoNames database to geocode scientific author addresses at the city level.

Overall, we were able to geocode 97% of inventor addresses at the city or a more accurate level, and 96% of scientific author addresses at the city level. Table 1 provides an overview of the geocoding results for the top 20 countries that account for most of the inventor and scientific author addresses. As can be seen in the table, the coverage of geocoded addresses is above 95% in most cases and falls below 90% only once.

Figures 1 and 2 in the 'Clusters by Patent and Scientific Publishing Performance and Cluster Rankings' annex at the end of this section (the Annex) visualize the geocoded locations of inventors and scientific authors, respectively, by depicting the density of geocoded addresses per 100 square kilometres. The two figures highlight how certain regions—notably parts of South America, Africa, and the Middle East—display relatively more activity in scientific publishing than patenting.

Identifying clusters and measuring their size

As in our 2017 analysis, we rely on the density-based algorithm for discovering clusters originally proposed in Ester et al. (1996), also known as the 'DBSCAN algorithm'. In applying the algorithm, we treated multiple listings of the same address—for example, the same inventor/author being listed in multiple patents/articles—as separate data points.

In addition, we gave equal weight to inventors and authors by expressing data points as a share of total inventor and author addresses, respectively. Given that the number of scientific articles far exceeds the number of patents, cluster identification on the basis of the raw data points would have resulted in cluster shapes heavily dominated by the scientific author landscape. Of course, our equal weighting approach is somewhat arbitrary. However, as will be shown later, patenting and scientific publishing activity correlates positively and, in any case, most clusters reflect patterns of overall economic agglomeration, so the identity of most clusters would probably have stayed the same if we had opted for different weights.[7]

Compared with our patent-based 2017 analysis, the inclusion of scientific articles helped to disambiguate the shape of clusters. In particular, the identification of clusters in certain densely populated areas—notably Frankfurt–Mannheim in Germany and New York in the United States of America (U.S.)—was highly sensitive to the chosen density parameters when focusing only on inventors. With both inventors and scientific authors included, the shape of the clusters was comparatively less sensitive to the chosen input parameters.

In the end, we settled on baseline input parameters of 15 kilometres (radius) and 4,500 density (minimum number of data points). These parameters effectively replicate last year's density while accounting for the substantially higher number of observations in this year's dataset. The DBSCAN algorithm then identified 198 clusters worldwide. Notwithstanding the reduced ambiguity in cluster identity, there were still a number of contiguous clusters. As last year, we applied co-inventor relationships to decide whether to combine two clusters into one. This led us to merge clusters in six cases, reducing the final list to 192 clusters covering 43 economies.[8]

The greater number of clusters compared with last year largely reflects the inclusion of geographical areas seeing substantial scientific publishing activity but comparatively less patenting activity, especially in middle-income economies, as illustrated in Figures 1 and 2 in the Annex.

Finally, we ranked the 192 clusters by counting the number of patents and scientific articles accounted for by the inventors and authors present in a given cluster. In doing so, we adopted a fractional counting approach, whereby counts reflect the share of a patent's inventors and an article's authors present in a particular cluster. In addition, mirroring our equal weighting approach described above, we express counts relative to the total numbers of patents and scientific articles.

The top 100 science and technology clusters

Annex Table 1 presents our top 100 cluster rankings. Although there are some notable changes, the inclusion of scientific publications did not dramatically alter the identity and size of clusters. Notably, nine of the top 10 clusters included in last year's rankings are still among the top 10 in the new rankings. Tokyo–Yokohoma still comes out on top and continues to have a wide margin over 2nd ranked Shenzhen–Hong Kong. Beijing—the cluster showing the greatest scientific publishing activity—rose in the rankings; San Diego, in turn, fell, reflecting its relatively weaker publishing performance. The New York cluster rose to 8th place; this largely reflects and expansion of the cluster to include the Princeton, NJ area.

Annex Table 2 presents the rankings for patent and scientific publishing performance separately, and Figure 3 in the Annex compares the two indicators for the top 100 clusters. The figure shows a strong positive correlation. Clusters that excel in scientific activity generally also account for more patent filings. Notably, top-ranked Tokyo–Yokohama is the top-performing patenting cluster and the 2nd ranked scientific publishing cluster.

However, some clusters show notably stronger performance for one of the two measures of science and technology activity. At one extreme, Eindhoven—the home of Philips Electronics— shows a relatively strong patenting performance far out of line with its relatively weak scientific publishing performance. At the other extreme, Tehran excels in scientific publishing activity, but shows relatively weak patenting output. Similarly, Figure 3 in the Annex points to other clusters located in middle-income countries that, albeit less extremely, also show comparatively stronger scientific publishing performance and that did not feature in last year's top 100. These include, for example, Ankara, Changchun, Delhi, Harbin, Hefei, Istanbul, São Paulo, and Xi'an.

The top 100 features clusters from 28 economies. The U.S., with 26 clusters, accounts for the highest number, followed by China (16), Germany (8), the United Kingdom (4), and Canada (4). Interestingly, there are only three Japanese clusters in the top 100, even if those three are the top-ranked Tokyo–Yokohama cluster and the highly ranked Osaka–Kobe-Kyoto and Nagoya clusters. In addition to China, there are clusters from five middle-income countries— Brazil, India, the Islamic Republic of Iran, the Russian Federation, and Turkey—in the top 100. Annex Figures 4, 5, and 6 offer zoomed-in visualizations of the East Asian, European, and North American clusters featuring in the top 100.

Annex Table 1 presents key characteristics of the top 100 clusters. In particular, it shows the top field of scientific publishing, the top organizations with which scientific authors are affiliated, the top patenting field, and the top patent applicant. Many patterns are the same we reported on last year: the largest patent applicant is typically a company; several companies constitute the top applicant for more than one cluster; and the share of patents accounted for by the top applicant differs substantially across clusters.[9]

Compared with last year, there is a shift in the distribution of top patenting fields. In particular, pharmaceuticals is now the most frequent top patenting field; it features as the top field in 22 clusters. Because pharmaceutical research and development (R&D) relies heavily on scientific input, the incorporation of scientific publications has led to the inclusion of clusters with vibrant scientific activity in this field. Pharmaceuticals is followed by digital communications and medical technology, which were the top two patenting fields last year; this year they each feature in 16 clusters.

Looking at the top fields of scientific publishing, the prominence of the life sciences is even more pronounced. Chemistry features as the top field in 36 clusters, even if not all chemistry research necessarily relates to the life sciences. In addition, the top science field in another 34 clusters relates to either medical research or pharmaceuticals. Engineering and physics are the remaining top technology fields, with 15 and 12 clusters each, respectively.

There is some correspondence between the top science field and the top patenting field. For example, both Shenzhen–Hong Kong and Seoul feature engineering as the top science field and digital communication as the top patenting field. Similarly, for Washington, DC–Baltimore, MD, oncology as the top science field relates to pharmaceuticals as the top patenting field. However, there are many cases for which the two fields do not seem to correspond. More generally, the top science field accounts for less than 10% of all scientific publications in most clusters, and the shares of the top science fields are typically below those of the top patenting fields. This suggests that clusters' scientific activities are more diverse than their patenting activities.[10]

Concluding remarks

This chapter has presented a new ranking of the world's top science and technology 100 clusters showing the greatest agglomeration of inventors and scientific authors. Building on last year's analysis, which focused solely on international patent filings, we incorporated scientific publication data into the identification and measurement of clusters. This has enriched the measurement approach and broadened the analysis to science and technology activity at large.

With an equal weight assigned to patenting and scientific publication activity, the resulting top 100 list looks in many ways similar to last year's list. This is especially the case for the top 10, which hardly changed. It arguably reflects underlying patterns of urbanization in the—mostly developed—countries that account for most innovative activity. However, the revised top 100 list includes clusters not present in last year's rankings. Among them are a number of clusters from middle-income countries that show substantial publishing activity but do not exhibit strong patenting output.

Many of the caveats outlined in last year's chapter continue to apply.[11] In addition, we acknowledge that the weighting of patenting and scientific publishing activity is arbitrary. While different weights would not lead to dramatic changes in the top half of the rankings, it would lead to noticeable changes in the lower half. From this viewpoint, we again caution that the current ranks should be best interpreted as orders of magnitude, with clusters moving up and down a few ranks depending on different weighting schemes and cluster parameter choices.

For the future, we aim to improve and broaden our analysis in at least two ways. First, we will continue to be on the lookout for other measures of innovative activity that could be included in the analysis. Second, we will strive to provide greater insight into the knowledge networks that are behind the spatial clusters we identify through our density-based approach. The richness of the patenting and scientific publication datasets—which include many variables not yet explored in our analysis—offers promising avenues to pursue this research.

Notes

1 Bergquist et al., 2017.

2 See GII model variables 6.1.4 and 6.1.5, which cover the number and quality of publications by country.

3 Garfield, 1970, 1972.

4 For further information, see https://clarivate.com/products/web-of-science and https://www.elsevier.com/solutions/scopus, respectively.

5 Falagas et al., 2008; Harzing and Alakangas, 2016.

6 The GeoNames database is available at http://geonames.org/.

7 See also Chapter 1, Annex 1, on the equal weighting approach adopted in the GII.

8 In particular, we calculated the share of a cluster's co-inventors belonging to all the other clusters as well as to two noise categories—namely, co-inventors located within 80 kilometres of the cluster midpoint not belonging to any other cluster and co-inventors beyond 80 kilometres not belonging to any other cluster We then merged two clusters if two conditions were met for at least one of the clusters: first, the minimum distance between any two points of the two clusters was less than 5 kilometres; and second, the neighbouring cluster accounted for the largest share of co-inventors among all clusters plus the two noise categories. This procedure led us to merge Long Beach with Los Angeles, Rotterdam with Amsterdam, Kaohsiung with Tainan, Jerusalem with Tel Aviv, Baltimore, MD with Washington, DC, and Matsudo with Tokyo.

9 See Bergquist et al. (2017) for further discussion.

10 An important caveat here is that the categorizations of science fields and patenting fields are structured differently and the shares are thus not directly comparable.

11 Bergquist et al., 2017.

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SPECIAL SECTION ANNEX

CLUSTERS BY PATENT AND SCIENTIFIC PUBLISHING PERFORMANCE AND CLUSTER RANKINGS

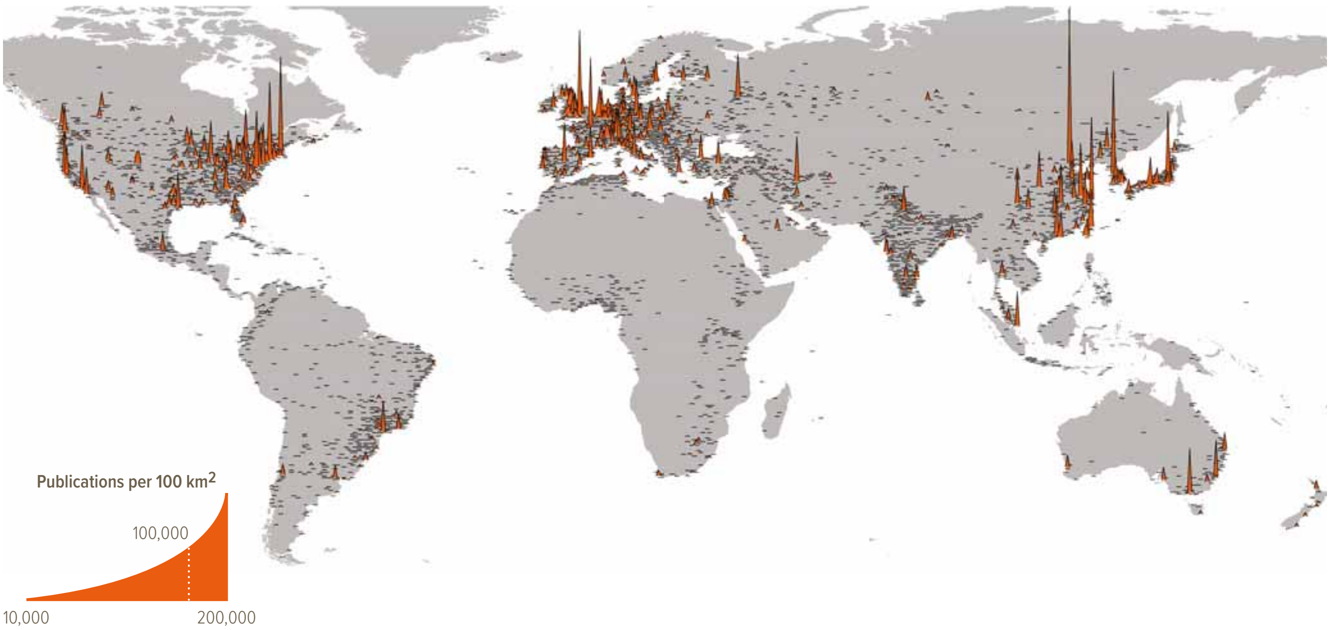
Figure 1.

PCT patent density per 100 square kilometres

Source: WIPO Statistics Database, March 2018.
Note: Patent filing counts refer to the 2012–16 period and are based on fractional counts, as explained in the text.

Figure 2.

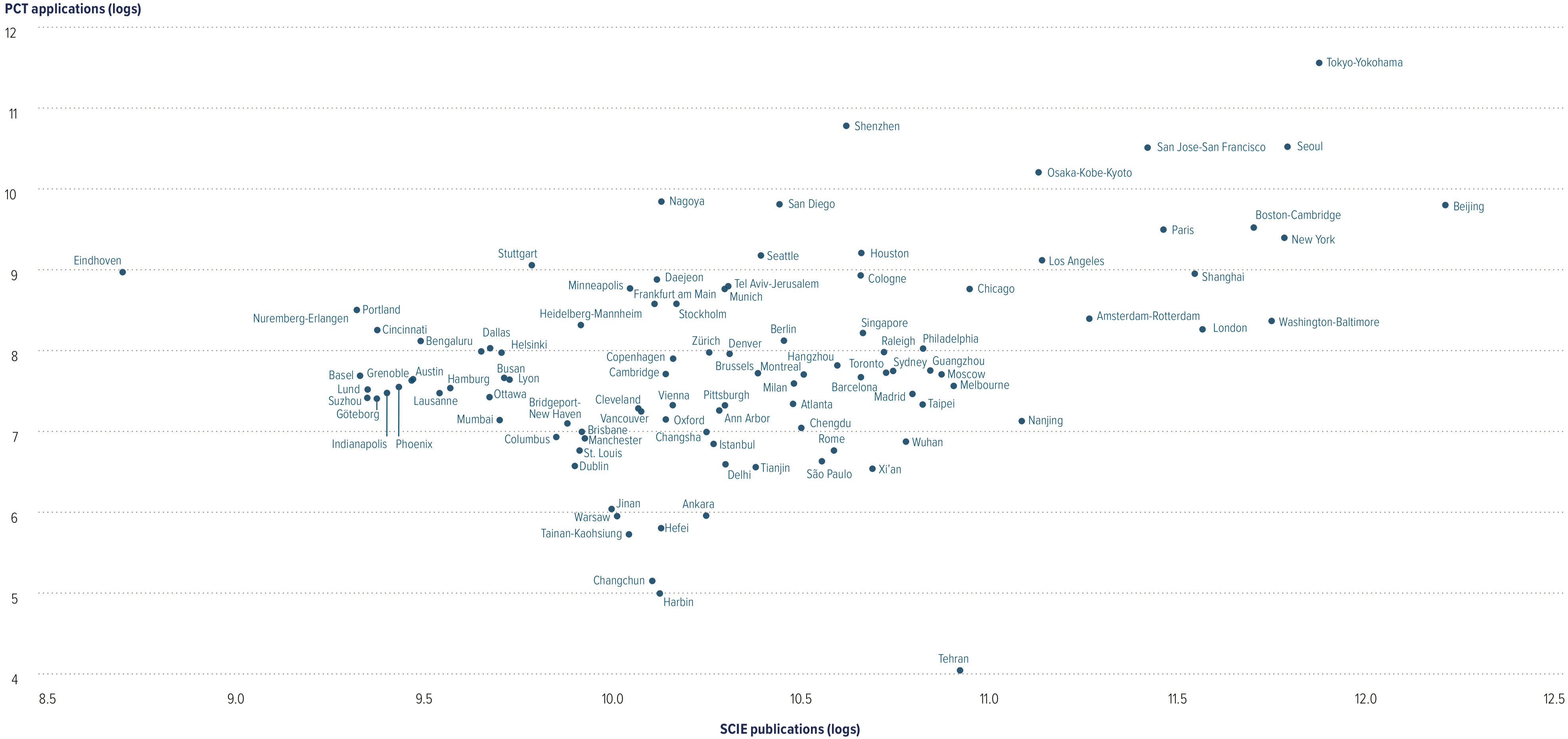
SCIE publication density per 100 square kilometres



Source: WIPO IP Statistics Database, March 2018.
Note: Publication counts refer to the 2012–16 period and are based on fractional counts, as explained in the text.

Figure 3.

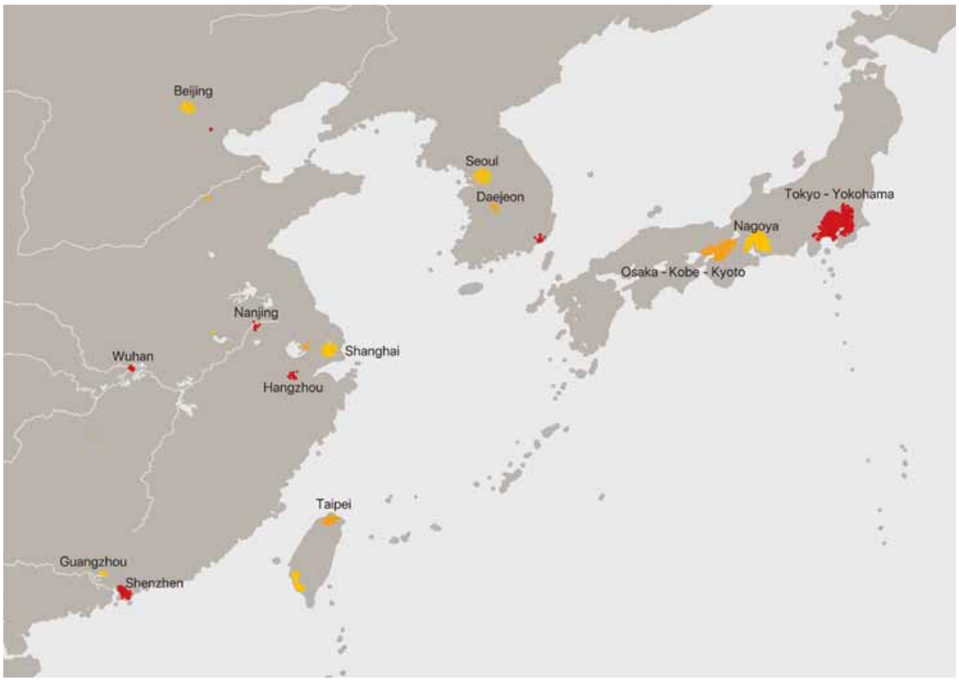
Patenting versus scientific publishing activity for the top 100 clusters



Note: Patent filing and scientific publication shares refer to the 2012–16 period and are based on fractional counts, as explained in the text.

Figure 4.

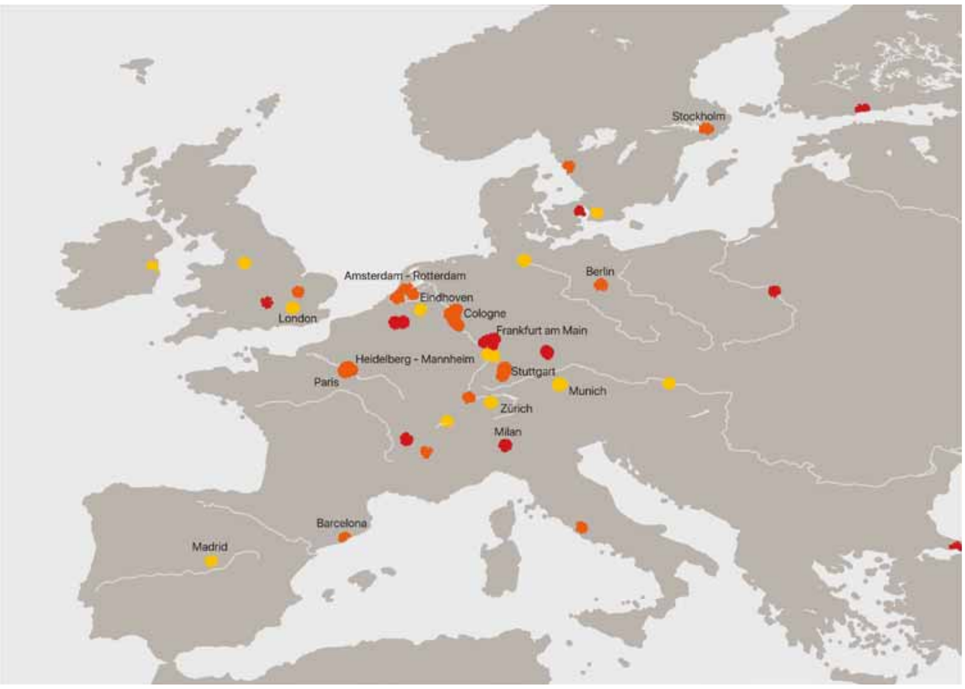
Regional clusters: Asia



Source: WIPO Statistics Database, March 2018.
Note: Colours have been assigned based on the colour of the nearest neighbours (in order to make clear the distinction between any two clusters).

Figure 5.

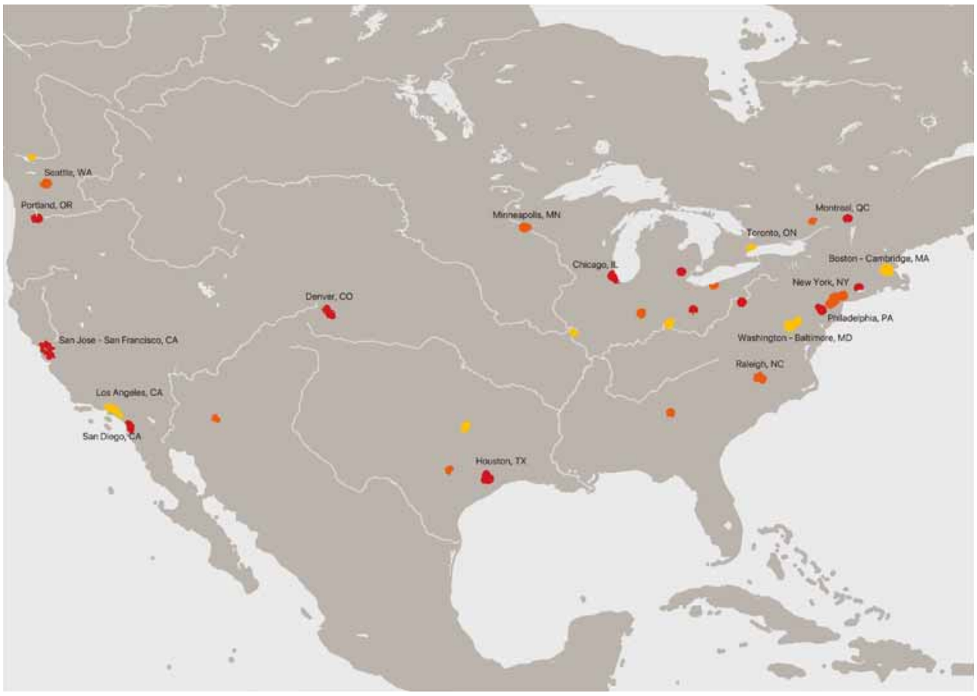
Regional clusters: Europe



Source: WIPO Statistics Database, March 2018.
Note: Colours have been assigned based on the colour of the nearest neighbours (in order to make clear the distinction between any two clusters).

Figure 6.

Regional clusters: Northern America



Source: WIPO Statistics Database, March 2018.
Note: Colours have been assigned based on the colour of the nearest neighbours (in order to make clear the distinction between any two clusters).

Table 1: Top 100 cluster rankings

						Scientific publishing performance				Patent performance			
Rank	Cluster name	Economies	Share of total PCT filings, %	Share of total pubs., %	Total	Top science field	Share, %	Top scientific organization	Share, %	Top patenting field	Share, %	Top applicant	Share, %
1	Tokyo–Yokohama	JP	11.00	1.77	12.77	Physics	9.43	University of Tokyo	13.95	Electrical machinery	9.83	Mitsubishi Electric	6.78
2	Shenzhen–Hong Kong	CN/HK	5.05	0.51	5.56	Engineering	10.71	University of Hong Kong	18.40	Digital communication	42.33	ZTE Corp.	30.41
3	Seoul	KR	3.90	1.63	5.53	Engineering	7.55	Seoul National University	16.27	Digital communication	15.77	LG Electronics	17.43
4	San Jose–San Francisco, CA	US	3.86	1.13	4.98	Chemistry	6.63	University of California	38.23	Computer technology	22.92	Google	7.18
5	Beijing	CN	1.90	2.46	4.36	Chemistry	10.65	Chinese Academy of Sciences	23.46	Digital communication	25.49	BOE Technology Group	21.09
6	Osaka–Kobe–Kyoto	JP	2.84	0.85	3.69	Chemistry	10.23	Kyoto University	22.05	Electrical machinery	14.05	Murata Manufacturing	10.26
7	Boston–Cambridge, MA	US	1.43	1.49	2.92	Oncology	5.88	Harvard University	53.77	Pharmaceuticals	16.90	M.I.T	6.45
8	New York, NY	US	1.26	1.61	2.88	Gen. & internal med.	5.97	Columbia University	13.29	Pharmaceuticals	14.38	Honeywell	4.69
9	Paris	FR	1.40	1.17	2.57	Physics	7.65	CNRS	22.16	Transport	11.63	L'Oréal	7.97
10	San Diego, CA	US	1.91	0.43	2.34	Chemistry	6.61	University of California	51.38	Digital communication	30.00	Qualcomm	57.30
11	Nagoya	JP	1.98	0.31	2.29	Physics	9.70	Nagoya University	33.86	Electrical machinery	17.62	Toyota	32.28
12	Shanghai	CN	0.81	1.27	2.09	Chemistry	13.67	Shanghai Jiao Tong University	22.96	Digital communication	10.62	Alcatel-Lucent	4.13
13	Washington, DC–Baltimore, MD	US	0.45	1.56	2.01	Oncology	5.24	Johns Hopkins University	22.37	Pharmaceuticals	17.60	Johns Hopkins University	14.53
14	Los Angeles, CA	US	0.96	0.85	1.81	Chemistry	5.69	University of California	44.21	Medical technology	18.10	University of California	5.78
15	London	GB	0.41	1.30	1.71	Gen. & internal med.	7.02	University of London	49.79	Digital communication	11.47	British Telecom	7.54
16	Houston, TX	US	1.05	0.53	1.58	Oncology	14.27	UTMD Anderson Cancer Center	29.54	Civil engineering	35.18	Halliburton	16.96
17	Amsterdam–Rotterdam	NL	0.46	0.97	1.43	Cardio. & cardiology	6.34	University of Utrecht	16.32	Civil engineering	6.24	Shell	8.94
18	Seattle, WA	US	1.02	0.41	1.42	Oncology	5.05	University of Washington	65.90	Computer technology	41.97	Microsoft Corp.	31.33
19	Chicago, IL	US	0.67	0.71	1.38	Chemistry	6.06	Northwestern University	27.02	Digital communication	8.38	Illinois Tool Works	15.01
20	Cologne	DE	0.79	0.53	1.32	Chemistry	6.89	University of Bonn	16.39	Basic materials chemistry	9.94	Henkel	8.62
21	Stuttgart	DE	0.90	0.22	1.12	Chemistry	7.33	University of Tubingen	44.53	Engines, pumps, turbines	14.05	Robert Bosch Corp.	47.99
22	Tel Aviv–Jerusalem	IL	0.69	0.37	1.07	Neurosciences	6.76	Tel Aviv University	33.98	Computer technology	17.12	Intel Corp.	4.46
23	Daejeon	KR	0.75	0.31	1.06	Engineering	13.49	KAIST	25.59	Electrical machinery	19.45	LG Chem	35.29
24	Munich	DE	0.67	0.37	1.04	Physics	8.11	University of Munich	55.04	Transport	11.49	BMW	13.57
25	Minneapolis, MN	US	0.68	0.29	0.97	Chemistry	6.06	University of Minnesota	74.37	Medical technology	29.69	3M Innovative Properties	35.12
26	Philadelphia, PA	US	0.32	0.62	0.95	Oncology	6.14	University of Pennsylvania	49.38	Pharmaceuticals	21.60	University of Pennsylvania	10.01
27	Nanjing	CN	0.13	0.81	0.94	Chemistry	12.97	Nanjing University	18.98	Digital communication	10.94	Southeast University	8.81
28	Singapore	SG	0.39	0.53	0.92	Chemistry	10.77	National Univ. of Singapore	38.24	Computer technology	7.71	A*Star	17.81
29	Eindhoven	BE/NL	0.83	0.08	0.90	Engineering	14.91	Eindhoven Univ. of Technology	61.67	Medical technology	25.57	Philips Electronics	81.76
30	Moscow	RU	0.23	0.66	0.89	Physics	17.56	Russian Academy of Sciences	38.16	Computer technology	10.44	Yandex Europe	3.30

(Continued on next page)

Table 1: Top 100 cluster rankings *(continued)*

Rank	Cluster name	Economies	Share of total PCT filings, %	Share of total pubs., %	Total	Scientific publishing performance: Top science field	Share, %	Top scientific organization	Share, %	Patent performance: Top patenting field	Share, %	Top applicant	Share, %
31	Stockholm	SE	0.56	0.33	0.89	Chemistry	5.35	Karolinska Institutet	49.66	Digital communication	38.88	Ericsson	46.17
32	Guangzhou	CN	0.24	0.64	0.88	Chemistry	10.67	Sun Yat Sen University	29.39	Medical technology	8.25	South China U. of Tech.	6.60
33	Melbourne	AU	0.20	0.68	0.88	Gen. & internal med.	5.69	University of Melbourne	25.63	Pharmaceuticals	9.12	Monash University	4.98
34	Raleigh, NC	US	0.31	0.56	0.87	Oncology	4.88	University of North Carolina	50.66	Pharmaceuticals	12.10	Cree	9.31
35	Frankfurt am Main	DE	0.56	0.31	0.87	Physics	9.31	Goethe University Frankfurt	24.10	Medical technology	11.61	Merck Patent GmbH	9.56
36	Sydney	AU	0.24	0.58	0.82	Gen. & internal med.	5.82	University of Sydney	40.29	Medical technology	11.95	Cochlear	4.73
37	Toronto, ON	CA	0.24	0.57	0.81	Neurosciences	7.10	University of Toronto	80.99	Computer technology	12.48	Synaptive Medical	3.52
38	Madrid	ES	0.18	0.61	0.79	Chemistry	5.93	CSIC	15.90	Digital communication	14.74	Telefonica	10.85
39	Berlin	DE	0.35	0.43	0.79	Chemistry	7.40	Free University of Berlin	37.59	Electrical machinery	11.03	Siemens	11.98
40	Taipei	TW	0.16	0.62	0.78	Engineering	8.41	National Taiwan University	28.29	Pharmaceuticals	10.66	MediaTek	9.21
41	Hangzhou	CN	0.26	0.50	0.76	Chemistry	12.99	Zhejiang University	59.88	Computer technology	26.99	Alibaba Group	42.83
42	Barcelona	ES	0.23	0.53	0.76	Chemistry	5.39	University of Barcelona	29.10	Pharmaceuticals	10.94	Hewlett-Packard	13.55
43	Wuhan	CN	0.10	0.60	0.70	Chemistry	10.72	Huazhong Univ. of Sci. & Tech.	30.54	Optics	10.59	Huazhong Univ. of Sci. & Tech.	11.10
44	Tehran	IR	0.01	0.69	0.69	Engineering	15.65	Tehran Univ. of Med. Sciences	11.80	Medical technology	10.52	Gharooni, Milad	5.26
45	Milan	IT	0.23	0.46	0.69	Neurosciences	8.07	University of Milan	24.79	Pharmaceuticals	7.62	Pirelli Tyre S.p.A.	7.20
46	Heidelberg–Mannheim	DE	0.43	0.25	0.68	Oncology	9.18	University Heidelberg	61.08	Basic materials chemistry	12.74	BASF	42.27
47	Denver, CO	US	0.30	0.38	0.68	Meteor. & atmos. sci.	5.07	University of Colorado	56.38	Medical technology	13.74	University of Colorado	6.61
48	Zurich	CH/DE	0.31	0.36	0.66	Chemistry	8.28	ETH Zurich	40.20	Medical technology	8.31	Sika Technology AG	5.08
49	Portland, OR	US	0.52	0.14	0.66	Neurosciences	6.99	Oregon University	67.29	Computer technology	24.29	Intel Corp.	50.37
50	Montreal, QC	CA	0.21	0.44	0.65	Engineering	7.02	McGill University	42.72	Digital communication	17.12	Ericsson	9.48
51	Brussels	BE	0.24	0.40	0.64	Physics	4.75	KU Leuven	41.71	Pharmaceuticals	7.47	Procter & Gamble Company	4.93
52	Xian	CN	0.07	0.55	0.62	Engineering	13.54	Xi'an Jiaotong University	29.37	Digital communication	16.29	Xian Jiaotong University	11.97
53	Copenhagen	DK	0.28	0.32	0.61	Neurosciences	5.18	University of Copenhagen	73.02	Biotechnology	15.95	Novozymes	11.07
54	Atlanta, GA	US	0.16	0.44	0.61	Public health	6.08	Emory University	36.75	Medical technology	14.83	Georgia Tech Research	8.90
55	Rome	IT	0.09	0.49	0.59	Neurosciences	6.57	Sapienza University Rome	31.81	Pharmaceuticals	10.93	Bridgestone Corp.	7.07
56	Chengdu	CN	0.12	0.45	0.57	Chemistry	11.03	Sichuan University	44.52	Pharmaceuticals	12.12	Huawei	6.22
57	São Paulo	BR	0.08	0.48	0.56	Neurosciences	4.18	Universidade de Sao Paulo	46.91	Medical technology	8.44	Mahle Metal Leve	3.37
58	Nuremberg–Erlangen	DE	0.40	0.15	0.55	Chemistry	8.04	Univ. of Erlangen Nuremberg	67.34	Electrical machinery	16.35	Siemens	41.38
59	Cambridge	GB	0.23	0.32	0.55	Other science and tech.	6.98	University of Cambridge	73.39	Computer technology	13.08	ARM IP Limited	5.80
60	Pittsburgh, PA	US	0.16	0.37	0.53	Neurosciences	5.63	(PCSHE)	66.74	Medical technology	12.55	University of Pittsburgh	11.92
61	Dallas, TX	US	0.32	0.20	0.52	Cardio. & cardiology	6.12	U of Texas SW Medical Center	50.46	Civil engineering	17.60	Halliburton	16.61

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Table 1: Top 100 cluster rankings *(continued)*

						Scientific publishing performance				Patent performance			
Rank	Cluster name	Economies	Share of total PCT filings, %	Share of total pubs., %	Total	Top science field	Share, %	Top scientific organization	Share, %	Top patenting field	Share, %	Top applicant	Share, %
62	Cincinnati, OH	US	0.35	0.17	0.52	Pediatrics	6.15	University of Cincinnati	46.92	Medical technology	30.07	Procter & Gamble Company	44.54
63	Ann Arbor, MI	US	0.15	0.37	0.52	Chemistry	5.29	University of Michigan	89.57	Transport	9.61	University of Michigan	25.07
64	Helsinki	FI	0.31	0.21	0.51	Neurosciences	4.49	University of Helsinki	57.08	Digital communication	31.32	Nokia Corp.	16.15
65	Bengaluru	IN	0.31	0.20	0.51	Chemistry	12.99	Indian Institute of Science	30.63	Computer technology	24.05	Hewlett-Packard	11.11
66	Vienna	AT	0.16	0.32	0.48	Physics	4.87	Medical University of Vienna	28.61	Pharmaceuticals	9.35	Siemens	3.95
67	Tianjin	CN	0.07	0.40	0.48	Chemistry	18.89	Tianjin University	29.16	Pharmaceuticals	10.95	Tianjin University	10.54
68	Changsha	CN	0.11	0.35	0.47	Chemistry	10.97	Central South University	42.30	Civil engineering	17.60	Zoomlion	36.38
69	Istanbul	TR	0.10	0.36	0.46	Engineering	6.59	Istanbul University	21.08	Pharmaceuticals	29.06	Bilgic, Mahmut	12.56
70	Oxford	GB	0.13	0.32	0.45	Physics	7.47	University of Oxford	78.64	Pharmaceuticals	10.01	Isis Innovation Limited	23.74
71	Cleveland, OH	US	0.15	0.30	0.45	Cardio. & cardiology	7.98	Cleveland Clinic Foundation	47.59	Medical technology	15.13	Cleveland Clinic	10.91
72	Delhi	IN	0.08	0.37	0.45	Chemistry	7.37	All India Inst. of Med. Sciences	14.50	Pharmaceuticals	15.25	Ranbaxy Laboratories	9.08
73	Vancouver, BC	CA	0.15	0.30	0.45	Neurosciences	4.70	Univ. of British Columbia	70.40	Medical technology	8.91	Univ. of British Columbia	7.12
74	Lyon	FR	0.22	0.21	0.43	Chemistry	7.46	CNRS	30.14	Organic fine chemistry	10.92	IFP Energies nouvelles	10.15
75	Busan	KR	0.22	0.21	0.43	Engineering	9.61	Pusan National University	39.27	Electrical machinery	7.71	Pusan National University	4.51
76	Ankara	TR	0.04	0.35	0.39	Cardio. & cardiology	5.51	Hacettepe University	17.01	Computer technology	12.40	Aselsan	23.46
77	Austin, TX	US	0.22	0.16	0.38	Chemistry	11.73	University of Texas Austin	83.72	Computer technology	23.39	University of Texas System	11.68
78	Grenoble	FR	0.22	0.16	0.38	Physics	18.03	CNRS	42.04	Electrical machinery	14.50	CEA	42.37
79	Hamburg	DE	0.20	0.18	0.38	Physics	8.11	University of Hamburg	57.70	Organic fine chemistry	17.84	Henkel	10.01
80	Ottawa, ON	CA	0.18	0.20	0.38	Engineering	6.31	University of Ottawa	56.78	Digital communication	42.42	Huawei	26.70
81	Bridgeport–New Haven, CT	US	0.13	0.25	0.37	Neurosciences	6.19	Yale University	86.33	Pharmaceuticals	15.09	Bristol-Myers Squibb	12.95
82	Basel	CH/DE/FR	0.23	0.14	0.37	Pharma. & pharmacy	7.66	University of Basel	61.33	Pharmaceuticals	19.06	F. Hoffmann-La Roche AG	12.51
83	Brisbane	AU	0.11	0.26	0.37	Engineering	5.31	University of Queensland	49.90	Civil engineering	13.41	University of Queensland	9.77
84	Manchester	GB	0.11	0.26	0.36	Chemistry	6.63	University of Manchester	65.09	Electrical machinery	15.68	MicroMass	14.50
85	Lausanne	CH/FR	0.19	0.18	0.36	Chemistry	8.20	EPFL	47.70	Food chemistry	9.86	NESTEC	27.79
86	Phoenix, AZ	US	0.20	0.16	0.36	Neurosciences	6.87	Arizona State University	50.84	Computer technology	13.67	Intel Corp.	16.63
87	Tainan–Kaohsiung	TW	0.03	0.31	0.35	Engineering	11.47	National Cheng Kung Univ.	32.09	Pharmaceuticals	14.89	MediaTek	7.55
88	Columbus, OH	US	0.11	0.24	0.35	Oncology	5.70	Ohio State University	89.80	Pharmaceuticals	13.20	Abbott Laboratories	14.98
89	St. Louis, MO	US	0.09	0.25	0.34	Neurosciences	6.72	Washington University	69.64	Biotechnology	16.35	Monsanto Technology	14.95
90	Lund	SE	0.19	0.15	0.34	Other science and tech.	5.12	Lund University	87.00	Digital communication	20.08	Ericsson	20.18
91	Indianapolis, IN	US	0.19	0.15	0.34	Oncology	5.48	Indiana University	67.90	Basic materials chemistry	11.33	Dow AgroSciences	21.55
92	Mumbai	IN	0.13	0.21	0.34	Chemistry	16.22	Bhabha Atomic Research Center	24.16	Organic fine chemistry	19.48	Piramal Enterprises	6.17

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Table 1: Top 100 cluster rankings *(continued)*

Rank	Cluster name	Economies	Share of total PCT filings, %	Share of total pubs., %	Total	Scientific publishing performance				Patent performance			
						Top science field	Share, %	Top scientific organization	Share, %	Top patenting field	Share, %	Top applicant	Share, %
93	Harbin	CN	0.02	0.31	0.33	Engineering	11.39	Harbin Institute of Tech.	43.69	Measurement	14.46	Harbin Institute of Tech.	42.64
94	Dublin	IE	0.08	0.25	0.33	Gen. & internal med.	17.10	Trinity College Dublin	30.49	Computer technology	11.36	Alcatel-Lucent	8.41
95	Changchun	CN	0.02	0.31	0.32	Chemistry	25.64	Jilin University	57.03	Measurement	11.36	Changchun Railway Vehicles	16.23
96	Gothenburg	SE	0.17	0.15	0.32	Engineering	7.28	University of Gothenburg	45.54	Digital communication	12.40	Ericsson	21.53
97	Hefei	CN	0.03	0.29	0.32	Physics	16.12	Univ. of Science & Technology	42.30	Electrical machinery	13.34	Anhui Jianghuai Automobile	12.05
98	Warsaw	PL	0.04	0.28	0.32	Chemistry	9.37	Polish Academy of Sciences	19.34	Pharmaceuticals	8.87	IBB Pan	3.71
99	Jinan	CN	0.04	0.28	0.32	Chemistry	14.57	Shandong University	60.58	Electrical machinery	10.38	Shandong University	10.04
100	Suzhou	CN	0.17	0.15	0.32	Chemistry	17.86	Suzhou University	69.82	Electrical machinery	9.88	Ecovacs Robotics	5.06

Notes: Patent filing and scientific publication shares refer to the 2012–16 period and are based on fractional counts, as explained in the text. We use the location of inventors to associate patent applicants to clusters; note that addresses of applicants may well be outside the cluster(s) to which they are associated. The identification of technology fields relies on the WIPO technology concordance table linking International Patent Classification (IPC) symbols with 35 fields of technology (available at http://www.wipo.int/ipstats/en/). The top scientific field is based on SCIE's Extended Ascatype subject field. An article can be assigned to more than one subject field. Fractional counting was used when more than one subject was assigned to an article. Codes refer to the ISO-2 codes. See page 37 for a full list, with the following addition: TW = Taiwan, Province of China. CEA = Commissariat a l'Energie Atomique; CNSR = Centre National de la Recherche Scientifique; IBB Pan = Instytut Bio Chemii I Biofizki Pan; PCSHE = Pennsylvania Commonwealth System of Higher Education.

Table 2: Cluster rankings by patent and publishing performance

Top 100 clusters ranked by patents

Patent rank	Cluster name	Economies	Number of patents
1	Tokyo–Yokohama	JP	104,746
2	Shenzhen–Hong Kong	CN/HK	48,084
3	Seoul	KR	37,118
4	San Jose–San Francisco, CA	US	36,715
5	Osaka–Kobe–Kyoto	JP	27,046
6	Nagoya	JP	18,837
7	San Diego, CA	US	18,217
8	Beijing	CN	18,041
9	Boston–Cambridge, MA	US	13,659
10	Paris	FR	13,318
11	New York, NY	US	12,032
12	Houston, TX	US	9,972
13	Seattle, WA	US	9,668
14	Los Angeles	US	9,113
15	Stuttgart	DE	8,574
16	Eindhoven	BE/NL	7,868
17	Shanghai	CN	7,718
18	Cologne	DE	7,554
19	Daejeon	KR	7,181
20	Tel Aviv–Jerusalem	IL	6,610
21	Minneapolis, MN	US	6,432
22	Munich	DE	6,389
23	Chicago, IL	US	6,385
24	Stockholm	SE	5,318
25	Frankfurt am Main	DE	5,312
26	Portland, OR	US	4,928
27	Amsterdam–Rotterdam	NL	4,423
28	Washington, DC–Baltimore, MD	US	4,302
29	Heidelberg–Mannheim	DE	4,089
30	London	GB	3,878
31	Nuremberg–Erlangen	DE	3,842
32	Singapore	SG	3,706
33	Berlin	DE	3,371
34	Cincinnati, OH	US	3,356
35	Dallas, TX	US	3,070
36	Philadelphia, PA	US	3,056
37	Bengaluru	IN	2,952
38	Raleigh, NC	US	2,926
39	Zürich	CH/DE	2,914
40	Helsinki	FI	2,906
41	Denver, CO	US	2,863
42	Copenhagen	DK	2,697
43	Hangzhou	CN	2,482
44	Guangzhou	CN	2,330
45	Sydney	AU	2,317
46	Toronto, ON	CA	2,268
47	Brussels	BE	2,254
48	Cambridge	GB	2,231
49	Moscow	RU	2,221
50	Milan	IT	2,218

Top 100 clusters ranked by scientific publications

Publication rank	Cluster name	Economies	Number of publications
1	Beijing	CN	197,175
2	Tokyo–Yokohama	JP	141,584
3	Seoul	KR	130,290
4	New York, NY	US	129,214
5	Washington–Baltimore, MD	US	124,968
6	Boston–Cambridge, MA	US	119,240
7	London	GB	104,238
8	Shanghai	CN	102,132
9	Paris	FR	94,073
10	San Jose–San Francisco, CA	US	90,238
11	Amsterdam–Rotterdam	NL	77,445
12	Los Angeles	US	68,404
13	Osaka–Kobe–Kyoto	JP	67,781
14	Nanjing	CN	64,856
15	Chicago, IL	US	56,564
16	Tehran	IR	55,156
17	Melbourne	AU	54,251
18	Moscow	RU	52,549
19	Guangzhou	CN	51,013
20	Philadelphia, PA	US	50,056
21	Taipei	TW	50,002
22	Madrid	ES	48,682
23	Wuhan	CN	47,857
24	Sydney	AU	46,272
25	Toronto, ON	CA	45,426
26	Raleigh, NC	US	45,176
27	Xi'an	CN	43,830
28	Singapore	SG	42,747
29	Houston, TX	US	42,568
30	Barcelona	ES	42,518
31	Cologne	DE	42,497
32	Shenzhen–Hong Kong	CN/HK	40,920
33	Hangzhou	CN	39,968
34	Rome	IT	39,615
35	São Paulo	BR	38,381
36	Milan	IT	36,596
37	Chengdu	CN	36,362
38	Montreal, QC	CA	35,666
39	Atlanta, GA	US	35,583
40	Berlin	DE	34,743
41	San Diego, CA	US	34,340
42	Seattle, WA	US	32,705
43	Brussels	BE	32,449
44	Tianjin	CN	32,261
45	Denver, CO	US	30,124
46	Tel Aviv–Jerusalem	IL	30,017
47	Delhi	IN	29,802
48	Pittsburgh, PA	US	29,758
49	Munich	DE	29,740
50	Ann Arbor, MI	US	29,317

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Table 2: Cluster rankings by patent and publishing performance *(continued)*

Top 100 clusters ranked by patents				Top 100 clusters ranked by scientific publications			
Patent rank	Cluster name	Economies	Number of patents	Publication rank	Cluster name	Economies	Number of publications
51	Basel	CH/DE/FR	2,184	51	Istanbul	TR	28,886
52	Barcelona	ES	2,145	52	Zürich	CH/DE	28,554
53	Lyon	FR	2,127	53	Changsha	CN	28,351
54	Austin, TX	US	2,093	54	Ankara	TR	28,327
55	Busan	KR	2,081	55	Stockholm	SE	26,200
56	Grenoble	FR	2,059	56	Copenhagen	DK	25,972
57	Montreal, QC	CA	1,984	57	Vienna	AT	25,949
58	Melbourne	AU	1,925	58	Oxford	GB	25,478
59	Phoenix, AZ	US	1,900	59	Cambridge	GB	25,475
60	Hamburg	DE	1,874	60	Nagoya	JP	25,186
61	Lund	SE	1,842	61	Tainan–Kaohsiung	TW	25,168
62	Indianapolis, IN	US	1,765	62	Harbin	CN	25,081
63	Lausanne	CH/FR	1,762	63	Daejeon	KR	24,891
64	Madrid	ES	1,743	64	Frankfurt am Main	DE	24,736
65	Ottawa, ON	CA	1,676	65	Changchun	CN	24,591
66	Suzhou	CN	1,661	66	Vancouver, BC	CA	23,885
67	Gothenburg	SE	1,645	67	Cleveland, OH	US	23,705
68	Atlanta, GA	US	1,542	68	Minneapolis, MN	US	23,195
69	Taipei	TW	1,530	69	Hefei	CN	23,130
70	Vienna	AT	1,518	70	Warsaw	PL	22,422
71	Pittsburgh, PA	US	1,514	71	Jinan	CN	22,101
72	Cleveland, OH	US	1,457	72	Manchester	GB	20,601
73	Ann Arbor, MI	US	1,421	73	Brisbane	AU	20,441
74	Vancouver, BC	CA	1,404	74	Heidelberg–Mannheim	DE	20,386
75	Oxford	GB	1,272	75	St. Louis, MO	US	20,318
76	Mumbai	IN	1,262	76	Dublin	IE	20,068
77	Nanjing	CN	1,246	77	Bridgeport–New Haven, CT	US	19,679
78	Bridgeport–New Haven, CT	US	1,211	78	Columbus, OH	US	19,113
79	Chengdu	CN	1,146	79	Stuttgart	DE	17,924
80	Brisbane	AU	1,092	80	Busan	KR	16,908
81	Changsha	CN	1,089	81	Lyon	FR	16,670
82	Columbus, OH	US	1,023	82	Helsinki	FI	16,555
83	Manchester	GB	1,006	83	Mumbai	IN	16,475
84	Wuhan	CN	967	84	Dallas, TX	US	16,068
85	Istanbul	TR	940	85	Ottawa, ON	CA	16,042
86	Rome	IT	866	86	Bengaluru	IN	15,696
87	St. Louis, MO	US	866	87	Hamburg	DE	14,471
88	São Paulo	BR	758	88	Lausanne	CH/FR	14,069
89	Delhi	IN	730	89	Cincinnati, OH	US	13,389
90	Dublin	IE	715	90	Austin, TX	US	13,124
91	Tianjin	CN	705	91	Grenoble	FR	13,076
92	Xi’an	CN	691	92	Phoenix, AZ	US	12,644
93	Jinan	CN	420	93	Indianapolis, IN	US	12,256
94	Ankara	TR	387	94	Nuremberg–Erlangen	DE	11,948
95	Warsaw	PL	384	95	Gothenburg	SE	11,934
96	Tainan–Kaohsiung	TW	331	96	Lund	SE	11,649
97	Hefei	CN	307	97	Suzhou	CN	11,638
98	Changchun	CN	173	98	Basel	CH/DE/FR	11,420
99	Harbin	CN	148	99	Portland, OR	US	11,323
100	Tehran	IR	57	100	Eindhoven	BE/NL	6,124

Notes: Patent filing and scientific publication counts refer to the 2012–16 period and are based on fractional counts, as explained in the text. Codes refer to the ISO-2 codes. See page 37 for a full list with the following addition: TW = Taiwan, Province of China.