

FACTBase

Bulletin 68, October 2019

Perth's Innovation Hotspots and Collaborations

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Introduction

Innovation is a key input to Australia's economy and industry. It is the result of various activities that are performed across all sectors of society, leading to either small incremental changes in processes and products or to large socio-economic and industrial structural shifts. In large structural changes, innovation may revolutionise society itself—such as Wi-Fi (which was invented by the Australian CSIRO), the Internet or Global Positioning Systems (GPS). Much of the knowledge, skills, technology and firm capital related to Western Australian (WA) innovation is located in Perth, which is understandable given that this is where most of the industry, population, governance, research and development infrastructure is found. Consequently, Perth has become a hub for the knowledge created, disseminated and applied across the State or sold to the globe through consultancies or corporate joint ventures.

Perth's competencies are traditionally associated with resource-related knowledge and technological capacities, particularly in mining, energy and agricultural sectors. However, the State's priorities have meant that wealth is not

Summary of Key Findings

- Innovation is a key input across the entire Australian economy and all industries, ensuring global competitiveness. Perth is the hub of such activities for Western Australia.
- Innovation is hard to measure because it is usually not recorded. One proxy for innovation is the number of patents by region, which allows national and global comparisons.
- The advent of the Internet and social networking web platforms is likely to have influenced the level of innovative and collaborative activity. Therefore, examining time periods before and after this event can be useful.
- Australia's innovation levels have remained nominally similar since 1999, unlike the surge found in other nations.
- While Perth does less patenting than other cities, it most likely innovates in a unique global space. This is related to its specialised resource economy.
- There appears to be an inverse relationship between Perth's economic wealth and patenting activity.
- There was significant patent growth across Greater Perth in the two periods of 1984–1998 and 1999–2013. There was also a rising spatial concentration of patent activity particularly in Perth city centre.
- Spatial patterns for patenting collaboration have become less centralised. It is likely that social networking platforms facilitated the growth and deepening of spatial networks more evenly across Greater Perth.
- Policy needs to strengthen spatial and virtual connectivity to enable the growth of strategic innovation hotspots and/or knowledge brokering hubs throughout Greater Perth, and not just in select areas.

always re-invested into the research and development of these industries, but is rather invested in infrastructure for better resource extraction (see Tonts et al., 2013; Martinus, 2018a). Nonetheless, there is increasing pressure to improve WA's innovative capacity. In particular, innovation is of strategic importance to future-proofing Perth because

it supports a more skilled and qualified workforce, while also attracting foreign and domestic investment (see Martinus and Guo, 2019).

This FACTBase Bulletin focuses on understanding innovation in Perth through a frequently used proxy to measure innovation—patent applications, which were extracted from the OECD

Regional Patent (REGPAT) statistics (OECD, 2016). While not all patent applications will be granted a license, they do provide a suitable indicator of *overall innovative activity*. Given that patent application costs are a barrier to applying for a patenting license, we assume that all applicants were engaged in some level of innovative activity, even if the patent was not granted by the World Intellectual Property Organisation (WIPO).

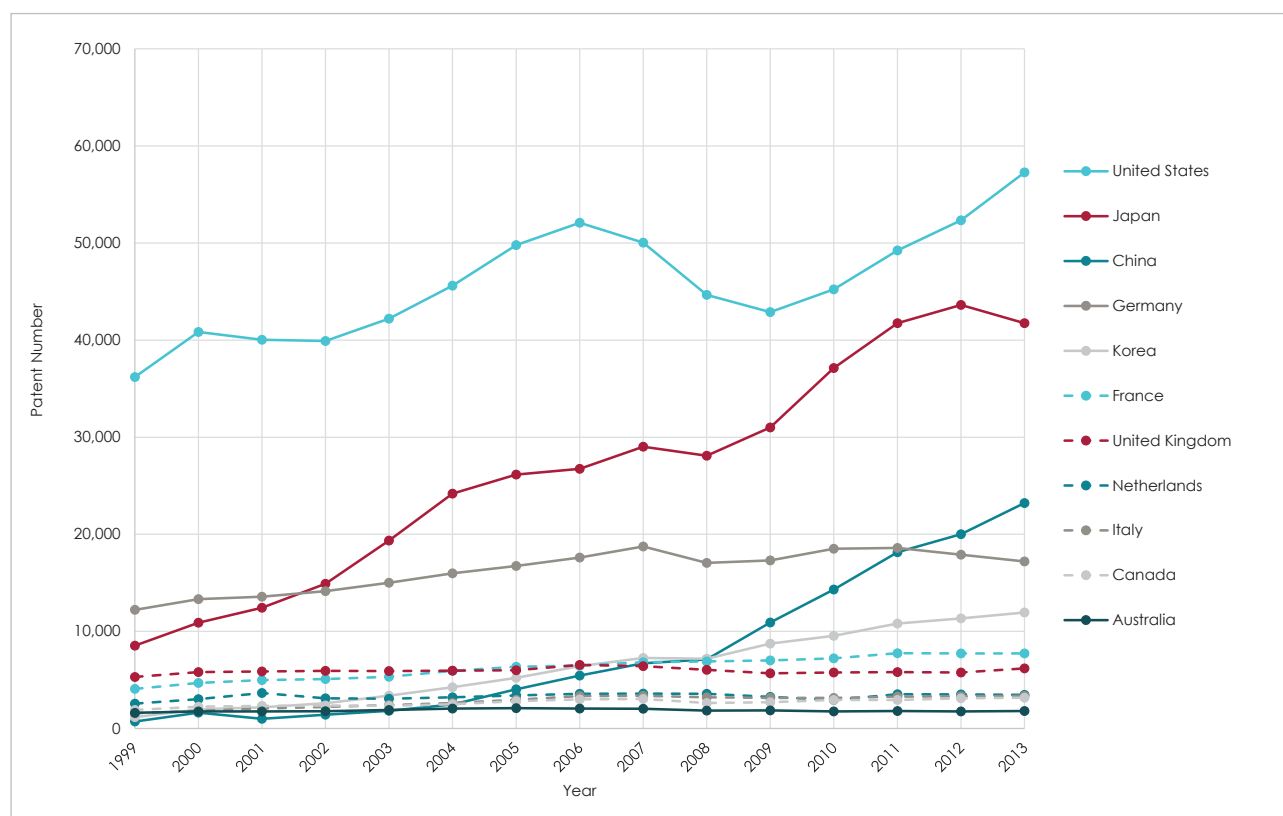
This Bulletin is divided into two main sections. The first section uses 1999–2013 REGPAT data to assess Perth's relative position in emerging technology innovations. This includes an analysis of where Western Australia sits in relation to the other Australian States, and also where Australia sits in relation to other nations. The second section examines local government area (LGA)

innovation hotspots across Perth using a social networks analysis for the periods of 1984–1998 and 1999–2013. These time periods represent data taken before and after online social networking platforms became popular global communication tools. The second section explores patent applicant collaborative activity across Perth and Peel LGAs, identifying where knowledge is aggregated and which regions act as mediators of knowledge exchange. We then aggregate the applicants at the capital city spatial level to examine the collaborative activity between the eight Australian State and Territory capitals. This Bulletin concludes with observations of the overall spatial distribution and connectivity of innovative activity within Perth and the nation. It then discusses implications and recommendations for WA's innovation policy.

How Innovative is Perth from a National and Global Perspective?

Perth's innovativeness needs to be understood at both a national and international level, which can be done by examining patent applications under the WIPO Patent Cooperative Treaty. Figure 1 below displays the patent levels over the 1999–2013 period for the top 10 OECD nations in 2013 and Australia (which is 15th). Social networking Internet platforms became a popular global communication tool in 1999, roughly. Consequently, there was likely to be a spike in innovative activity after this time, with ideas, knowledge and techniques flowing more freely around the globe.

Figure 1: Number of patent applications filed under the Patent Cooperative Treaty (PCT), 1999–2013



Adapted from: OECD (2016)

Interestingly, innovation in Australia was on par with China and Korea in 1999. Although China and Korea have since had a rapid increase in patenting, innovation in Australia has remained nominally similar over time. The differences in the patenting trajectories of these three nations perhaps reflect a stronger policy shift towards innovation in China and Korea than Australia. Indeed, while China was the least active in patenting in 1999 of our subset of nations, it ranked third by 2013.

The most innovative countries since 1999 have been the United States and Japan. Japan's rapid rise suggests that it may challenge the United States' leading position in the future. Interestingly, patenting appeared to grow at varying degrees after 2008 among the nations in the top six spots. This suggests that the economic downturn of the global financial crisis may have positively impacted innovative activity. In 2013, Australia ranked 15th among the 46 OECD countries of the REGPAT dataset.

By examining the technology type of Australian innovations, we find that most patenting activity during 1999–2013 was in infrastructure communication technology (ICT), which was followed by medical technology, pharmaceuticals, biotechnology, and nanotechnology (see Figure 2 and Table 1). However, Australia appears to be well represented in the 'other technology' patenting category of the REGPAT dataset. Indeed, a similar analysis by IP Australia (2017) highlighted Australia's advanced manufacturing strength in electronics patenting (which included ICT), mechanical engineering, pharmaceuticals and medical devices. Although Sydney and Melbourne are the prime locations for this patenting given their strengths in biotechnology,

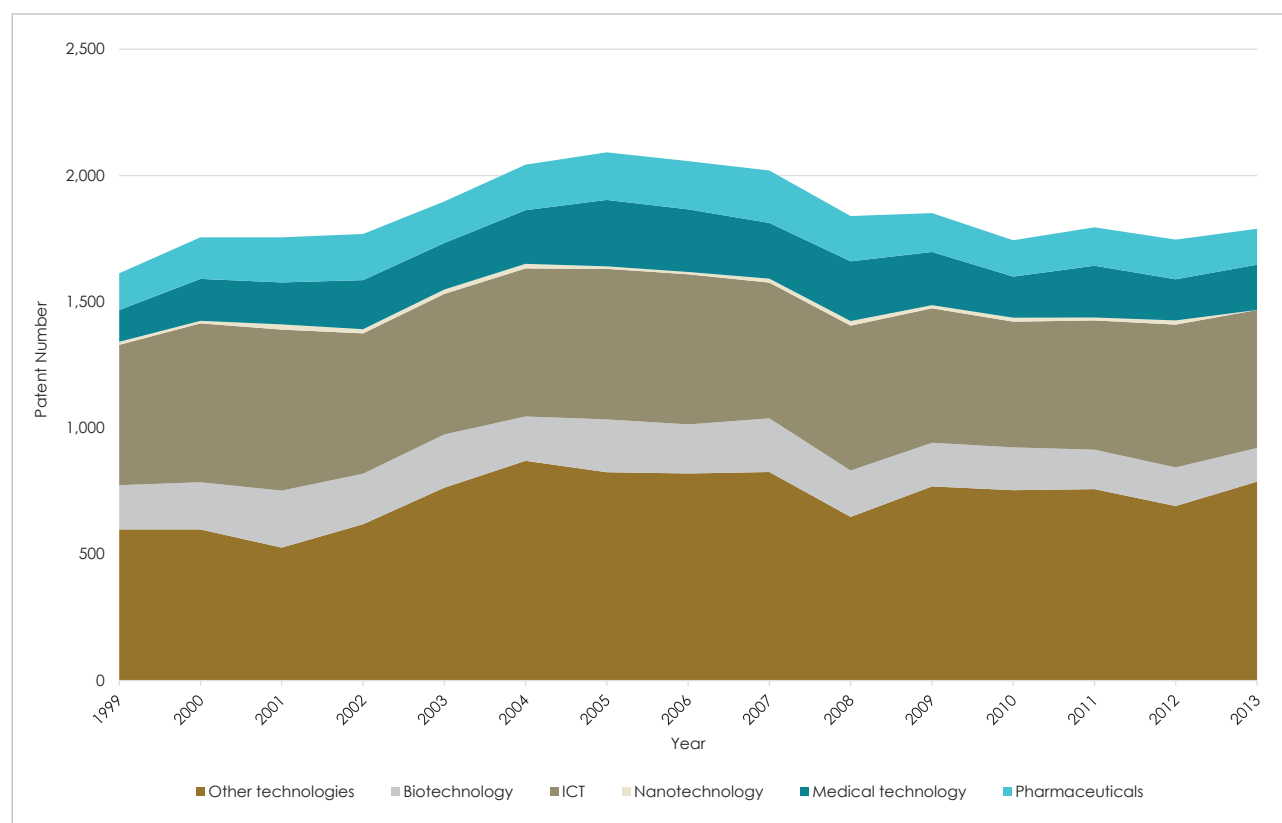
medical technology and pharmaceuticals, Perth may be the location for many of the patents in the 'other technology' category. IP Australia (2017) noted that 'Australia had a strong chemical engineering presence due to mining technologies', with this sector having 'the fewest number of applications globally' (p.14). Therefore, it is likely that Perth had a large role to play in the generation of these patents.

The global trend of increasing patents after 2008 (Figure 1) is not found in Australia. Instead, Figure 3 on page 5 shows that there was a sharp patenting decline in Sydney and a stagnation in Melbourne from 2007–2010, after which there was a slight increase. Interestingly, Brisbane and Perth followed the global trend after 2008, with Perth declining from 2011. This happened despite the surge in inward financial investments and trade exports from Perth, as noted in FACTBase Bulletin 65 (Martinus and Guo, 2019). This points to an inverse relationship between the wealth of Perth's economy and its patenting activity.

The respective patent trends of each Australian capital city (see Figure 3, with breakdown by technology in Table 2) reflects the differences in their State innovation policies and Research and Development (R&D) funding levels. Indeed, the comparatively high patent levels of Sydney and Melbourne are not surprising given that New South Wales and Victoria have the highest gross expenditure on R&D of all of the Australian States (Martinus, 2018b). Perth and Brisbane have swapped positions between third and fourth most active in patents over this time period. Currently ranked fourth, the Perth trend line may reflect its strong connection to the WA resource economy. In particular, the initial sharp increase from 2002–2007 may be the product of the State's

technological adjustments to facilitate the resource boom under severe labour shortages. After which, there are declines from the 2007–2008 global financial crisis and a small increase in 2009. Nonetheless, it is expected that Western Australia (and Perth) may experience an increase in patents in the future thanks to large corporate investments in robotics and other artificial intelligent mining technology (Gray, 2019). Of the technology patents identified by the OECD REGPAT data, while Perth has patented most in medical technologies, ICT and nanotechnology, its strengths appear to lie in the patenting of other technologies that are related to particular industry sectors, such as resources and rural health.

Figure 2: Australian patent applications filed under the PCT, by technology, 1999–2013¹



Adapted from: OECD (2016)

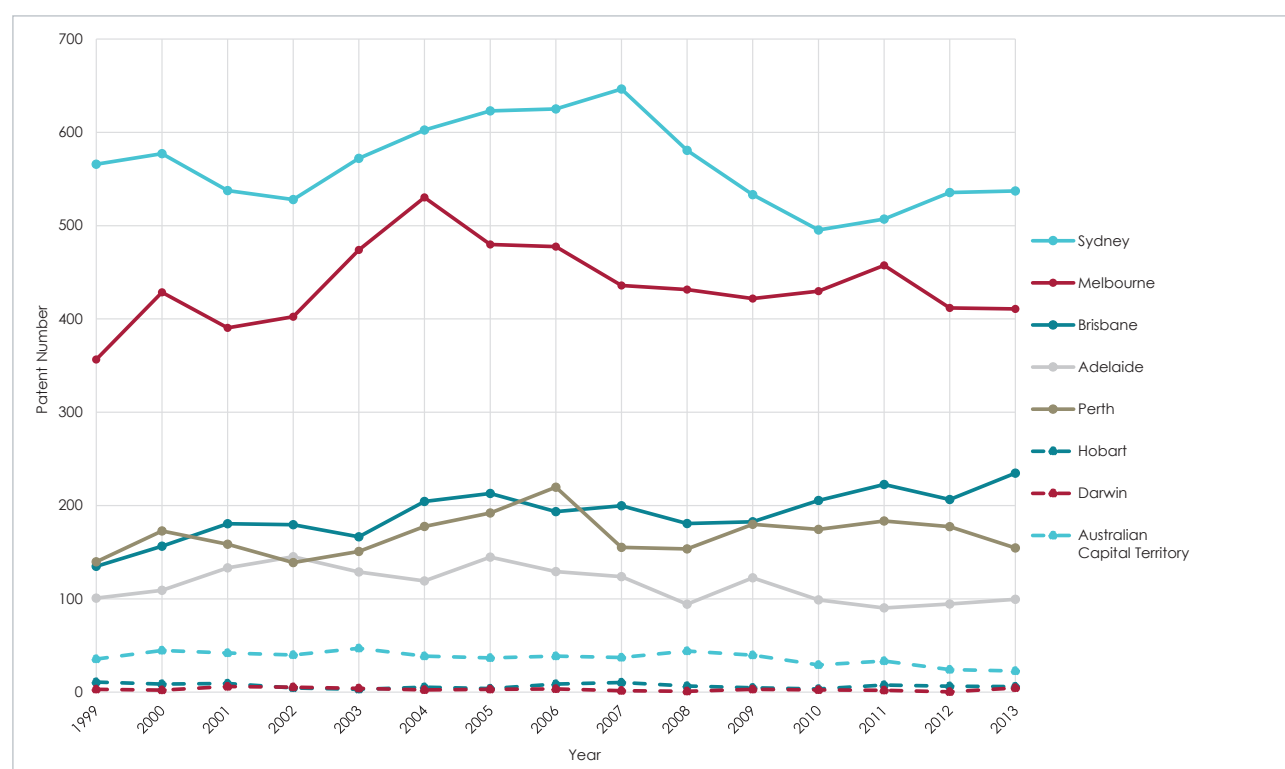
Table 1: Proportion of Australian patent applications filed under the PCT, by technology, 1999–2013

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Biotechnology	10.9%	10.6%	12.9%	11.3%	11.1%	8.6%	10.0%	9.5%	10.5%	10.0%	9.3%	9.7%	8.7%	8.8%	7.4%
Infrastructure communication technology	34.4%	35.9%	36.3%	31.4%	29.3%	28.7%	28.5%	28.9%	26.6%	31.2%	28.8%	28.5%	28.5%	32.4%	30.6%
Nanotechnology	0.8%	0.5%	1.2%	0.9%	0.9%	0.9%	0.5%	0.4%	0.8%	1.0%	0.6%	0.9%	0.6%	0.9%	-
Medical technology	7.8%	9.5%	9.5%	11.0%	9.7%	10.4%	12.6%	12.1%	10.9%	12.9%	11.4%	9.3%	11.4%	9.3%	10.1%
Pharmaceuticals	9.0%	9.3%	10.2%	10.3%	8.7%	8.8%	9.0%	9.3%	10.3%	9.8%	8.3%	8.3%	8.5%	9.0%	7.9%
Other technologies	37.1%	34.1%	30.0%	35.0%	40.2%	42.6%	39.4%	39.9%	40.9%	35.2%	41.6%	43.2%	42.2%	39.6%	44.0%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Adapted from: OECD (2016)

¹ 2013 data for nanotechnology was not available.

Figure 3: Total patents by Australian capital cities, 1999–2013



Adapted from: OECD (2016)

Table 2: Patents numbers and percent of Australian capital cities, by technology, 1999–2013

	Total		Biotechnology		ICT		Nanotechnology		Medical technology		Pharmaceuticals	
Sydney	8,466	30.5%	658	23.8%	3,446	41%	67	33%	1,310	44.6%	591	23.4%
Melbourne	6,539	23.6%	917	33.2%	2,048	24%	55	27%	562	19.1%	920	36.4%
Brisbane	2,861	10.3%	388	14.0%	723	9%	26	13%	242	8.2%	316	12.5%
Adelaide	1,733	6.2%	255	9.3%	550	6%	10	5%	139	4.7%	204	8.1%
Perth	2,528	9.1%	177	6.4%	569	7%	15	7%	241	8.2%	154	6.1%
Hobart	99	0.4%	6	0.2%	25	0%	0	0%	13	0.4%	8	0.3%
Darwin	44	0.2%	1	0.0%	7	0%	0	0%	3	0.1%	0	0.0%
Australian Capital Territory	553	2.0%	129	4.7%	257	3%	6	3%	46	1.6%	66	2.6%
Australia	27,761	100.0%	2,759	100.0%	8,476	100%	202	100%	2,940	100.0%	2,530	100.0%

Adapted from: OECD (2016)

Perth's Patent Hotspots and Innovation Networks

Innovations are not the product of sole endeavours at a single point of time, but instead emerge through the sustained efforts of an individual or group drawing on past experiences and networks. While it is not possible to know exactly how this comes together in a patent application, we can understand the innovativeness of locations by looking at the inventors' addresses on patent applications and the locations of their collaborators. To do this, we assigned OECD REGPAT Australian applicant postcodes to an LGA in WA or capital city or territory in Australia, excluding regional LGAs of States and Territories other than WA. LGA, city or territorial boundaries are taken to be those in 2019, and any changes in LGA boundaries between 1984 and 2013 do not affect how the data was distributed. Patents where more than one inventor was involved had several addresses associated with them. All of the applicants' addresses were included, with a weighting applied according to the number of inventors. For example, if five people were involved in patenting, then one fifth of the patent was assigned to each address. The patent addresses constituted a mix of business locations and individual residences.

The final list of patent locations was examined in two ways: first, by looking at differences between Perth LGAs; and second, by creating a social network map of all patent applicant collaborations by LGA. In the latter, we examine how LGAs across Western Australia are connected through innovative activity, as well as

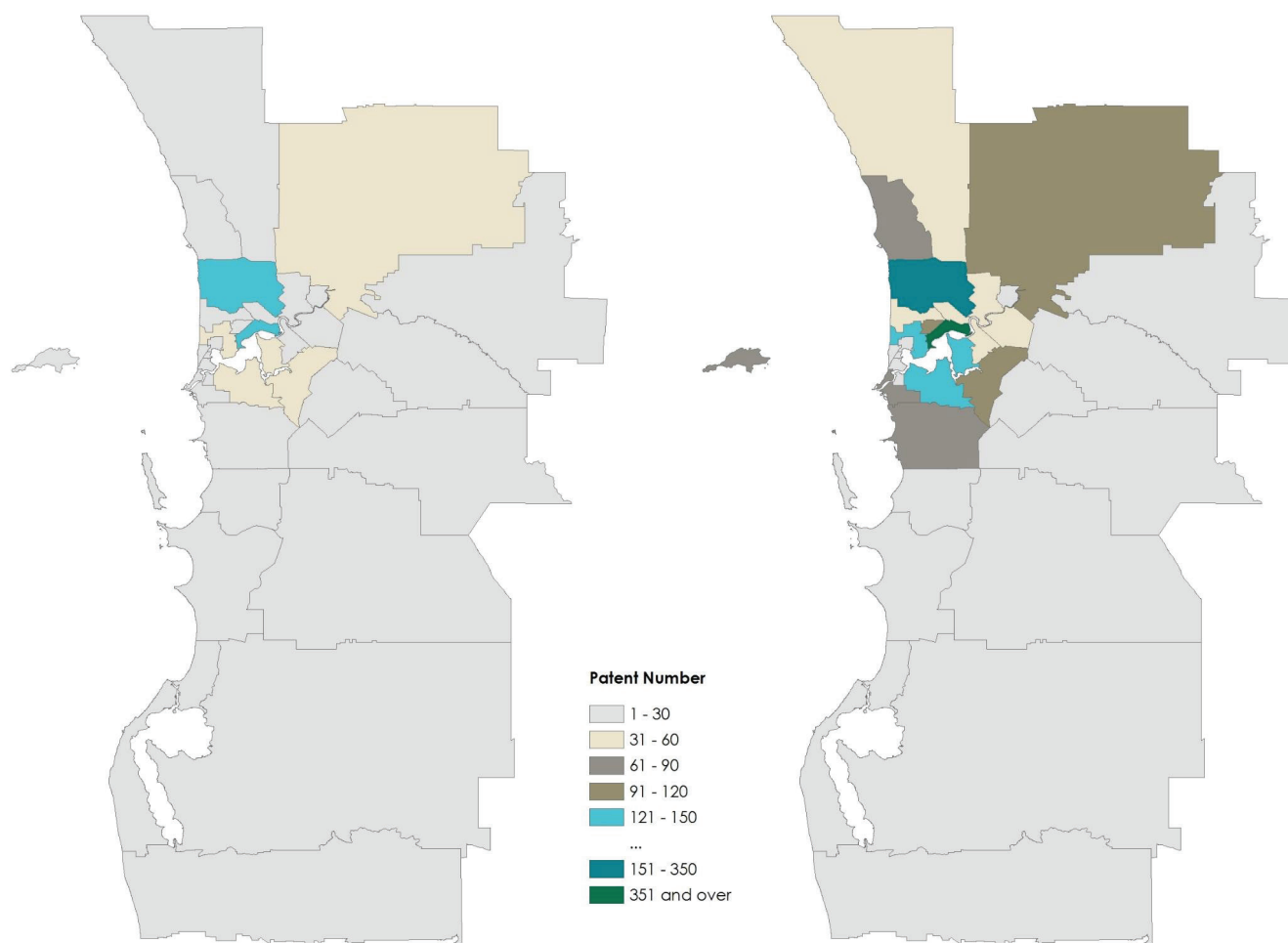
how Perth connects with the other Australian capital cities. The data was analysed by aggregating applicant locations in two periods of 1984–1998 and 1999–2013, which represent innovations before and after social media exploded as a networking and information gathering tool. For example, Messenger was launched in 1999, Wikipedia in 2001, LinkedIn in 2002, Facebook in 2004, Twitter in 2006, and Instagram in 2010. It was assumed that social media facilitated access to information and networks, including persons previously disadvantaged by location. Consequently, it can be predicted that social media facilitated greater connectivity, knowledge flows and collaborative activity, which led to more patenting after 1999.

Figure 4 on page 7 highlights applicant numbers in the two periods for Greater Perth LGAs. This is enumerated in Table 3, which shows the absolute and proportion of total LGA applications in each period, as well as their absolute and percentage change. Figure 4 and Table 3 include all persons registered to a single patent application within the two time periods. Surprisingly, Stirling was the top location for patent applicants in 1984–1998, followed by Perth city centre. Both of these locations had substantially more innovators than anywhere else in the Greater Perth region. The next cohort of patenting locations produced only around half, including Melville, South Perth, Nedlands, Canning and Swan. These top seven LGAs had around 63% of all the applicants.

By 1999–2013, Perth city centre had claimed the majority of applicant addresses, such that innovations appeared to be increasingly concentrated at this location. There was a significant increase in the gap between

the top and second innovating spots. Indeed, while Perth city centre rose from 15% to 23% of innovators, Stirling lost ground and fell from 17% to 13%. The other top innovation locations either experienced slight proportional gains or losses, while overall activity in Greater Perth increased dramatically with the top seven innovators producing 525 applications in 1984–1998 and 1,412 in 1999–2013 (or a change of 169%).

Figure 4: REGPAT patent distribution of Greater Perth LGAs, 1984–1998 (left) and 1999–2013 (right)



Adapted from: OECD (2016)

Table 3: Absolute and percent change in patent distribution of Greater Perth LGAs between 1984–1998 and 1999–2013, ranked by OECD REGPAT applicant numbers

1984–1998			1999–2013			Change 1984–1998 to 1999–2013		
LGA	Absolute	%	LGA	Absolute	%	LGA	Absolute	% Change
Stirling	145.4	17.32	Perth	496.5	22.74	Perth	372.5	300%
Perth	124	14.77	Stirling	287.1	13.15	Stirling	141.7	97%
Melville	59.1	7.04	Nedlands	141.4	6.48	Nedlands	89.8	174%
South Perth	52.7	6.28	South Perth	136.3	6.24	South Perth	83.6	159%
Nedlands	51.6	6.15	Melville	136	6.23	Melville	76.9	130%
Canning	50	5.96	Canning	117.5	5.38	Subiaco	69.6	252%
Swan	42	5.00	Subiaco	97.2	4.45	Canning	67.5	135%
Subiaco	27.6	3.29	Swan	92.4	4.23	Cockburn	56.5	459%
Bayswater	25	2.98	Cockburn	68.8	3.15	Swan	50.4	120%
Cambridge	25	2.98	Fremantle	66.5	3.05	Fremantle	41.5	166%
Fremantle	25	2.98	Joondalup	63.6	2.91	Joondalup	39.5	164%
Joondalup	24.1	2.87	Vincent	47.4	2.17	Vincent	38.4	427%
Belmont	22	2.62	Belmont	47	2.15	Belmont	25	114%
Wanneroo	18.8	2.24	Cambridge	45.6	2.09	Wanneroo	21.2	113%
Gosnells	17	2.03	Bayswater	42.3	1.94	Cambridge	20.6	82%
Claremont	16	1.91	Wanneroo	40	1.83	Murray	18.3	1830%
Victoria Park	13	1.55	Victoria Park	30.3	1.39	Bayswater	17.3	69%
Cockburn	12.3	1.47	Claremont	28.2	1.29	Victoria Park	17.3	133%
Rockingham	10.7	1.27	Gosnells	22.5	1.03	Armadale	13.6	162%
Cottesloe	10.3	1.23	Armadale	22	1.01	Kwinana	13.3	266%
Kalamunda	10	1.19	Murray	19.3	0.88	Claremont	12.2	76%
Vincent	9	1.07	Kwinana	18.3	0.84	Mosman Park	11.7	900%
Armadale	8.4	1.00	Bassendean	15.5	0.71	East Fremantle	11.5	1150%
Bassendean	8	0.95	Kalamunda	14.8	0.68	Mandurah	8	133%
Mundaring	8	0.95	Mandurah	14	0.64	Bassendean	7.5	94%
Mandurah	6	0.71	Rockingham	14	0.64	Mundaring	5.8	73%
Kwinana	5	0.60	Mundaring	13.8	0.63	Serpentine-Jarrahdale	5.8	145%
Waroona	5	0.60	Mosman Park	13	0.60	Gosnells	5.5	32%
Serpentine-Jarrahdale	4	0.48	East Fremantle	12.5	0.57	Kalamunda	4.8	48%
Mosman Park	1.3	0.15	Serpentine-Jarrahdale	9.8	0.45	Rockingham	3.3	31%
East Fremantle	1	0.12	Cottesloe	6.5	0.30	Peppermint Grove	0.3	30%
Murray	1	0.12	Waroona	2	0.09	Waroona	-3	-60%
Peppermint Grove	1	0.12	Peppermint Grove	1.3	0.06	Cottesloe	-3.8	-37%
Total	839.3	100%	Total	2,183.4	100%	Total	1,344.1	160.15%

Adapted from: OECD (2016)

Looking at the change over time, we observe that almost all LGAs became more innovative, except for Waroona and Cottesloe (falling by three and four patents, respectively). Some LGAs experienced extraordinary jumps in innovative activity. For example, Murray rose by 18 applications (or 1830%, as it moved from 1 to 19 patents). Meanwhile, East Fremantle and Mosman Park experienced increases of 1150% and 900%, respectively, which was once again due to jumps from small bases in the first period. Activity across the entire Greater Perth region increased by 1,344 patents or 160% overall between the two periods. Not surprisingly, Perth city centre appeared to benefit the most. Its increased spatial concentration in innovative activity is most likely the result of its high agglomeration of industry (largely in resources and advanced business services) compared to other LGAs. Stirling is unexpectedly second, ranking ahead of the strategic knowledge centres of Joondalup, Nedlands, Cockburn, Melville, South Perth and Fremantle—all which house major universities and medical knowledge infrastructure. This is most likely due to the mix of industry in Stirling (including medical), its adjacency to the city and its good transport connectivity.

The second part of this section examines the collaborations and network of each LGA across WA and of the eight Australian capital cities. Excluding single inventor patents, there were 257 patent collaborations among WA LGAs and 2,108 among the capital cities during the 1984–2013 period. The location-by-patent application matrix (two mode) for only those patents with a collaboration was transposed to a location-by-location matrix (one mode). This allowed inter-regional (LGA or city) collaborations to be understood through a social

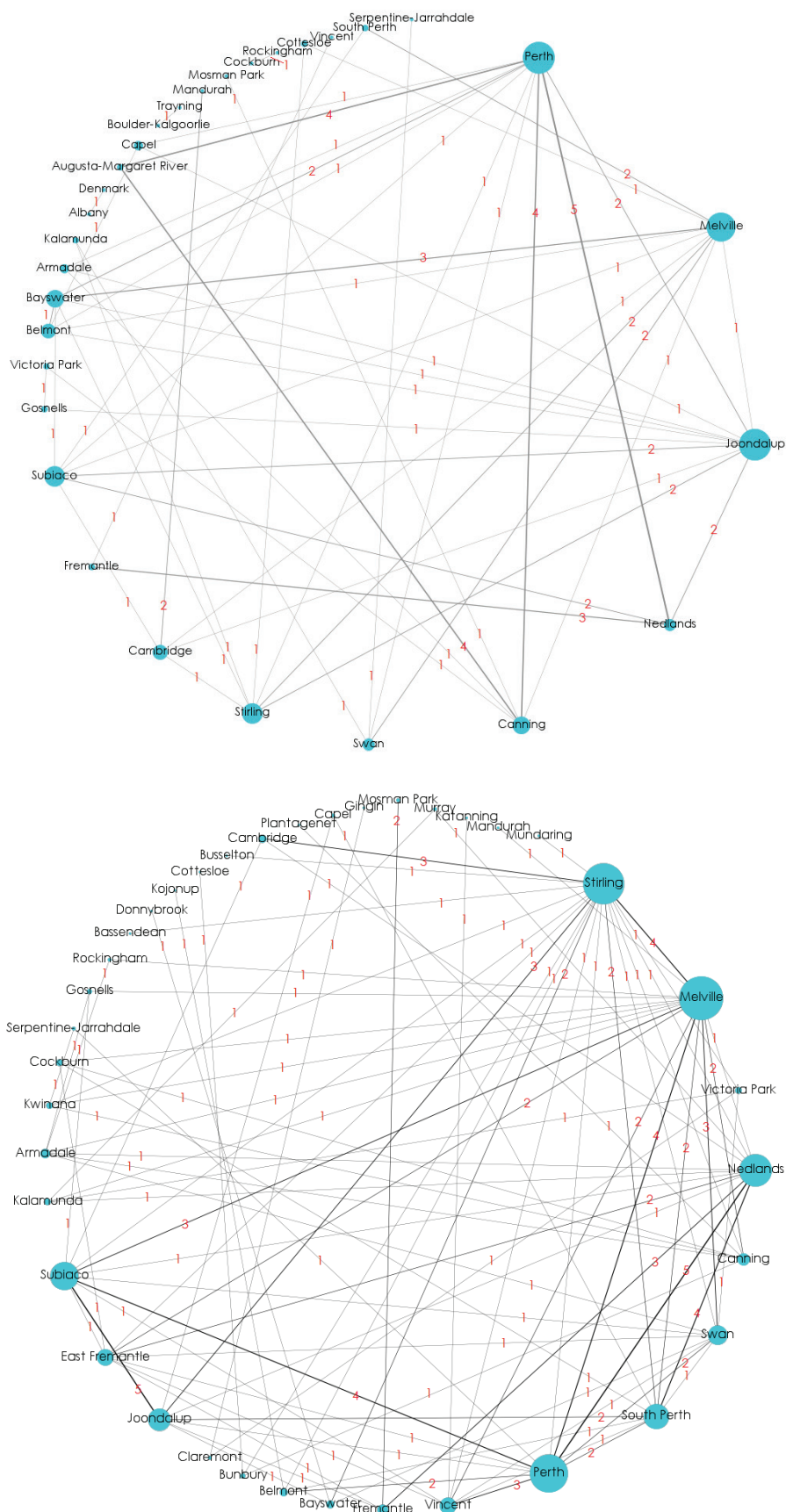
network analysis (SNA)² that can visualise networks and unpack relationships through centrality measures. Centrality measures explain why a specific node (or location in our analysis) is 'important' or 'central' in the context of an entire network (Newman, 2010). We employed the two measures of degree and betweenness centrality. Degree centrality indicates a region's (LGA or city) importance in the patent collaboration network by measuring how many other LGAs it connects to. Because it does not take into account the weight or number of collaborations of specific LGA-LGA connections, we also used a weighted degree centrality. This is the total number of all collaborations found between one node (an LGA) and all other nodes (other LGAs). A high degree centrality indicates where the majority of collaborations are and therefore where knowledge is most concentrated. Betweenness centrality is the degree to which a region acts as a *broker* or *gate keeper* to the knowledge flows between two other regions. Regions with a high betweenness centrality sit in the middle of the majority of the shortest path between any two other regions (or nodes), and are therefore highly important in facilitating interactions between other places.

Figure 5 and Table 4 on pages 10 and 11 present the results of the SNA between LGAs in regional WA and the Greater Perth region. Figure 5 uses a circular layout rather than a map, given that SNA looks at social relations rather than spatial and because it is easier to read the relationships. Nodes were ordered clockwise according to betweenness centrality, and node size was adjusted based on its weighted

degree centrality. The number of collaborations between each LGA are shown in red. During 1984–1998, Perth city centre had by far the highest degree and betweenness centralities. This is an indicator of its dominance and importance in the overall network in terms of capacity to aggregate knowledge and mediate knowledge flows between other LGAs. This is followed by Joondalup, Melville, Canning and Nedlands, pointing to the importance of the presence of education infrastructure (Edith Cowan University, Curtin University and The University of Western Australia are all found in or close to those LGAs), medical facilities (including Joondalup Health Campus, St John of God Murdoch and QEII Hospitals) and comparatively advantaged LGAs (both Melville and Nedlands are relatively wealthy areas). The next group of highly connected LGAs are primarily found in the Greater Perth inner and middle ring (Cambridge, Fremantle, Subiaco, Stirling and Belmont) and are associated with clusters of creative industries or specialised consultancies (e.g. around Subiaco), and mid or high-tech clusters of manufacturing (e.g. near airport or port facilities, or industrial parks of Stirling). These LGAs are also important mediators of exchange in the patent applicant network.

² We conducted the SNA using Gephi – an open source software package widely used for analysis and visualisation of large networks.

Figure 5. Network of patent collaborative activities across WA regional and Greater Perth LGAs, 1984–1998 (top) and 1999–2013 (bottom)



Adapted from: OECD (2016)

Table 4: Weighted degree and betweenness centrality of REGPAT applicant collaborative activity across WA regional and Greater Perth LGAs, 1984–1998 and 1999–2013, ranked by number of patent collaborations

1984–1998					1999–2013				
LGA	Weighted Degree Centrality		LGA	Betweenness Centrality	LGA	Weighted Degree Centrality		LGA	Betweenness Centrality
	No.	%				No.	%		
Perth city centre	23	14.20	Perth city centre	0.17	Melville	30	11.36	Stirling	0.42
Joondalup	15	9.26	Melville	0.13	Stirling	28	10.61	Melville	0.18
Melville	15	9.26	Joondalup	0.13	Perth city centre	26	9.85	Victoria Park	0.11
Canning	12	7.41	Nedlands	0.10	Nedlands	22	8.33	Nedlands	0.11
Nedlands	12	7.41	Canning	0.10	Subiaco	19	7.20	Canning	0.08
Bayswater	10	6.17	Swan	0.07	South Perth	17	6.44	Swan	0.06
Stirling	9	5.56	Stirling	0.06	Joondalup	15	5.68	South Perth	0.06
Subiaco	9	5.56	Cambridge	0.06	Swan	13	4.92	Perth city centre	0.06
Augusta-Margaret River	8	4.94	Fremantle	0.05	East Fremantle	11	4.17	Vincent	0.05
Belmont	6	3.70	Subiaco	0.04	Vincent	11	4.17	Fremantle	0.05
Cambridge	6	3.70	Gosnells	0.01	Canning	8	3.03	Bayswater	0.05
Swan	5	3.09	Victoria Park	0.01	Fremantle	7	2.65	Belmont	0.05
Fremantle	4	2.47	Belmont	0.004	Armadale	6	2.27	Bunbury	0.05
Armadale	3	1.85	Bayswater	0.003	Bayswater	5	1.89	Claremont	0.05
Capel	3	1.85	Armadale	0.002	Belmont	5	1.89	Joondalup	0.05
South Perth	3	1.85	Kalamunda	0.002	Cambridge	5	1.89	East Fremantle	0.04
Mandurah	2	1.23	Augusta-Margaret River	0	Cockburn	4	1.52	Subiaco	0.03
Victoria Park	2	1.23	Capel	0	Kwinana	4	1.52	Kalamunda	0.02
Cottesloe	2	1.23	South Perth	0	Victoria Park	4	1.52	Armadale	0.02
Gosnells	2	1.23	Mandurah	0	Kalamunda	4	1.52	Kwinana	0.02
Kalamunda	2	1.23	Cottesloe	0	Gosnells	3	1.14	Cockburn	0.004
Albany	1	0.62	Albany	0	Bunbury	3	1.14	Serpentine-Jarrahdale	0.001
Denmark	1	0.62	Denmark	0	Rockingham	2	0.76	Gosnells	0.0003
Boulder-Kalgoorlie	1	0.62	Boulder-Kalgoorlie	0	Capel	2	0.76	Cambridge	0
Trayning	1	0.62	Trayning	0	Claremont	2	0.76	Rockingham	0
Mosman Park	1	0.62	Mosman Park	0	Mosman Park	2	0.76	Capel	0
Cockburn	1	0.62	Cockburn	0	Murray	2	0.76	Mosman Park	0
Rockingham	1	0.62	Rockingham	0	Serpentine-Jarrahdale	2	0.76	Murray	0
Vincent	1	0.62	Vincent	0	Bassendean	1	0.38	Bassendean	0
Serpentine-Jarrahdale	1	0.62	Serpentine-Jarrahdale	0	Donnybrook	1	0.38	Donnybrook	0
Total	162	100			Total	264	100		

Interestingly, WA's wine regions of Augusta-Margaret River, Capel (both regional WA) and Swan (outer metro) are also highly connected (indicating importance in patenting). The low betweenness centrality of Augusta-Margaret River and Capel may point to the highly specialised nature of its patenting—where, despite a large number of collaborations, it does not mediate knowledge flows between regions. A similar pattern is found with other regional WA LGAs (e.g. Denmark and Kalgoorlie-Boulder), pointing to the significance of Perth city centre in facilitating flows across the WA innovation network.

The 1999–2013 period is comparatively denser with more regional and metropolitan LGAs included in the network, as well as more connections between them. Nonetheless, the distribution of these activities seemed to be less centralised and more evenly spread among the LGAs (e.g. see the percentage change in total collaborations between periods). These findings align with our hypothesis that the era of social media networking is associated with greater collaborative activity. Of particular note is the decline of Perth city centre as the most important node for collaborations and as broker of knowledge flows. Indeed, while Perth city centre rose from 23 to 26 total collaborations between the two periods, most other LGAs in the top positions rose more quickly. For example, Stirling went from 9 to 28, and Melville from 15 to 30. Furthermore, while the infrastructure associated with patent locations (e.g. specialised knowledge clusters or large infrastructures) changed relatively little, the capacity to innovate and the relationships between the locations did change. This latter point is particularly salient when examining the rank changes

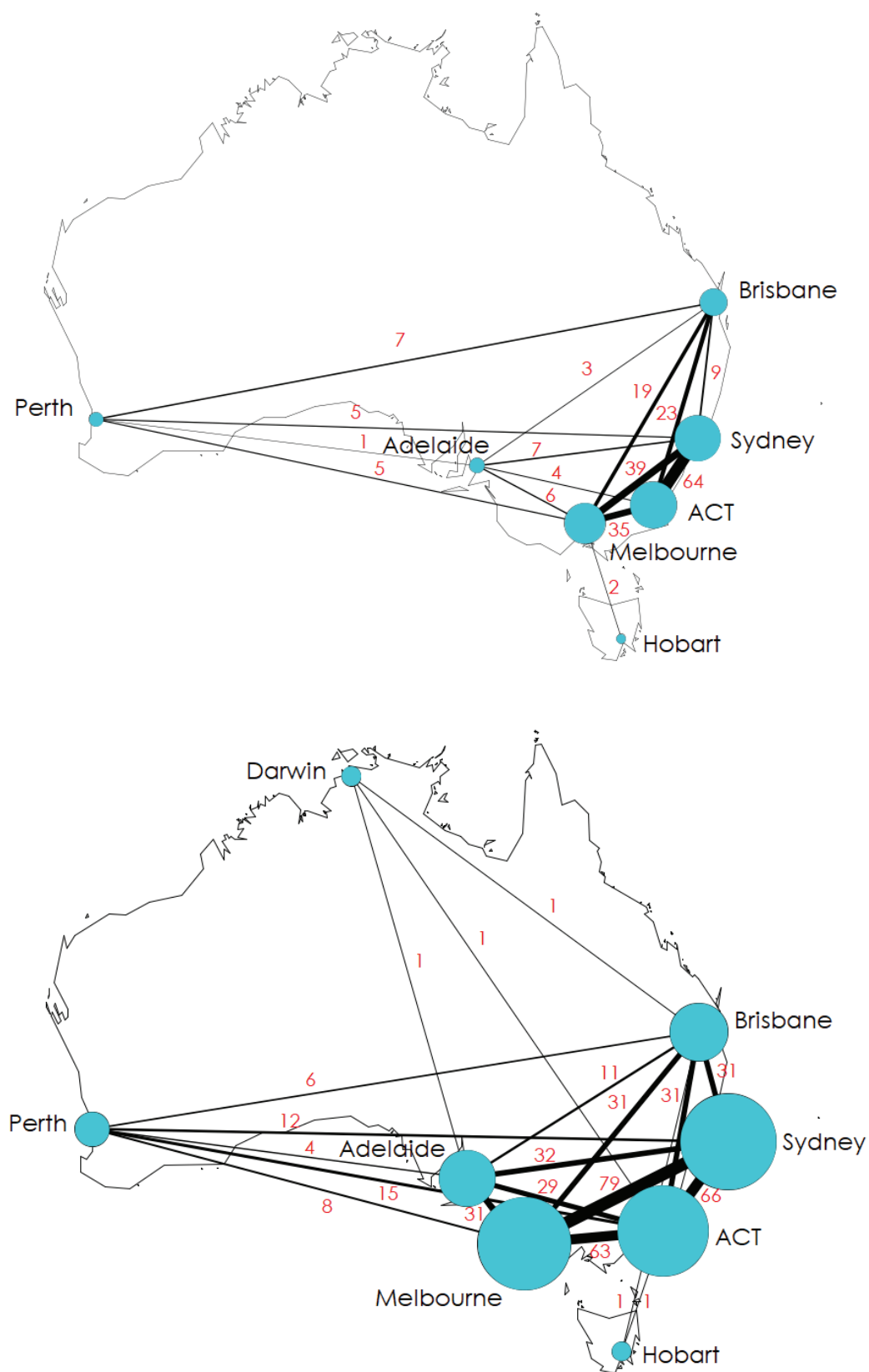
in the betweenness centrality measure, with Perth city centre falling to sixth in its knowledge brokerage role.

Furthermore, 1999–2013 appeared to have allowed new players to emerge, with Joondalup performing the same as in the 1984–1998 period (i.e., 15 collaborative patent applications filed in each period), but others such as Swan increased their collaborative efforts (from 5 to 15 collaborative patent applications filed). These differences in performance generated a new LGA line-up in knowledge brokers across the region, with Swan, Victoria Park and South Perth emerging as new hubs. Joondalup and Bayswater notably fell down the rankings, the former being the most surprising given its strong university, government and hospital facilities, as well as its important position in Greater Perth's urban hierarchy (see Department of Planning, Lands and Heritage, 2018). Interestingly, Stirling not only experienced a significant increase in collaborations but it also became the most centralised in terms of a brokerage role. This may reflect a combination of being close to Perth city centre, as well as the success of the knowledge infrastructure related to various industry clusters in Osborne Park, Scarborough, and so on. Victoria Park also rose as a key broker. However, unlike Stirling, it was not a strong collaborator itself. This appears to point to its unique role within Greater Perth in facilitating knowledge flows *between* other locations, rather than being a generator of patents itself.

Figure 6 and Table 5 on pages 13 and 14 highlight the spatial distribution and level of collaboration between Perth and other Australian capital cities over the respective time periods of 1984–1998 and 1999–2013.

During 1984–1998, Perth, Hobart and Adelaide were peripheral to the cross-national network of patent collaborations, with Sydney, Melbourne, Australian Capital Territory (ACT) and Brisbane serving as core network hubs. Darwin did not have any cross-national collaboration according to the REGPAT data. During the 1999–2013 period, all cities increased patent collaborative activities, except Hobart whose two collaborations shifted from Melbourne to ACT. However, as in the WA LGA analysis, there was a decrease in centralisation of the knowledge collaborative networks, such that activity was more evenly spread across the Australian cities (see percent weighted centrality measure in Table 5). While Perth and Darwin demonstrated only small increases, Adelaide rose significantly in number and proportion of the total, mainly due to more collaborations with other east coast capital cities (who also significantly increased their collaboration). Consequently, Perth appears to operate more independently and is less networked to the other cities than they are to each other. Interestingly, while ACT ranks poorly in terms of corporate headquarters and subsidiary locations (see, for example, Sigler and Martinus 2017, where ACT does not appear as significant in corporate networks of firms listed on the Australian Securities Exchange), it strongly contributed to Australia's collaborative innovation and knowledge networks.

Figure 6: Patent collaborative activity between Australian capital cities, 1984–1998 (top) and 1999–2013 (bottom)



Adapted from: OECD (2016)

Table 5: Comparison of weighted degree centrality of patent collaborative activity across Australian capital cities, 1984–1998 and 1999–2013

1984-1998				1999-2013			
City	Weighted Degree Centrality		Betweenness Centrality	City	Weighted Degree Centrality		Betweenness Centrality
	No.	%			No.	%	
ACT	126	27.51	0	Sydney	220	24.23	0
Sydney	124	27.07	0.02	Melbourne	212	23.35	0
Melbourne	106	23.14	0.35	ACT	206	22.69	0.17
Brisbane	61	13.32	0.02	Brisbane	112	12.33	0.17
Adelaide	21	4.59	0.02	Adelaide	108	11.89	0.05
Perth	18	3.93	0	Perth	45	4.96	0
Hobart	2	0.44	0	Darwin	3	0.33	0
Darwin	0	0.00	0	Hobart	2	0.22	0
Total	458	100		Total	908	100	

Conclusion

The wealth and prosperity of Perth has long been associated with its industry and resources. Indeed, government royalties, firm profits and worker incomes all stem from their various direct or indirect engagements with WA resource production and trade. In general, while cities at the heart of resource economies are traditionally subject to global market conditions and demand, they are interacting in increasingly complex ways internationally. Indeed, over recent decades, Perth has moved away from traditional resource extraction and production towards more knowledge-intensive and high-tech modes of operation. For example, using autonomous vehicles in super pit gold mines, cutting-edge deep-sea and off-shore extraction methods, and innovative project management and occupational, health and safety processes and procedures. These Australian skills and technology advancements in the resource sector are increasingly demanded and applied elsewhere through the trade of Australian products and services. The associated skills, knowledge and innovations

are the accumulation of local experience and Australian nationwide collaborations.

It is therefore of strategic interest to better understand both the degree to which a local economy innovates, and how it spatially connects to external knowledge and innovator networks. This FACTBase Bulletin explores this by mapping patenting within and across Perth, including how it connects to the rest of WA and the nation. However, patenting data only reports on the substantial innovations to protect intellectual property and not on the many other forms of innovation. Consequently, there may be a spatial bias with data being concentrated in cities where large corporations are located, or in certain industries where patenting is more prevalent (such as medical rather than creative or artistic industries). However, given the difficulties in obtaining data on other innovation types, patents can point to broader patterns at play (Martinus, 2018; Martinus et al., 2019).

Our analysis finds that, unlike the increases of top patenting nations over the 1999–2013 period, Australian patenting

activity has remained roughly the same and is among the strongest in ICT and 'other' technologies of OECD REGPAT technology patent categories. Disaggregating by Australian city, Perth appears to be one of the least innovative. This may be a product of its strong resource sector, with patenting activity remaining relatively stable throughout the 2004–2010 resource boom period. We then examined innovation changes in Perth between two time periods. The first being 1984–1998, when Internet social networking was not yet prevalent, and the second being 1999–2013, when social networking platforms and global access had become common use. We found a significant growth in patenting between these two periods across all Greater Perth LGAs, as well as a rising spatial concentration in some LGAs— particularly in the Perth city centre.

Nonetheless, there was an interesting shift away from Perth city centre as spatial collaboration patterns became less centralised. This implied that social networking may have facilitated the growth and deepening of spatial networks

compared to those of the 1984–1998 period, when spatial co-location or transport access had greater influence. Indeed, whereas the Perth city centre was the most important in terms of collaborations and the brokering of knowledge networks before 1999, it certainly did not hold this position after. Indeed, the LGA rankings of these measures produced unique insights into how knowledge networks spatially changed across Greater Perth, pointing to opportunities for LGAs to increase innovation through greater connectivity. Furthermore, an analysis of nationwide collaborative networks revealed that Perth was not only less innovative than other capital cities, but was also less connected. This was particularly evident when compared to Adelaide, which significantly outstripped the growth in collaborations compared to Perth between these two periods. This may be a product of Perth's spatial distance from the other cities, differences in industry composition and lower State priorities regarding innovation.

Understanding the strengths, spatial distribution and connectivity of Perth within the broader national and global context is critical in the formation of an appropriate policy to address these gaps. This includes policies to enhance specific areas of technology weakness or strengths relating to key industries where WA may have a global strategic advantage. Indeed, as noted in an IP Australia report, patenting in WA is associated with a technology where there are fewer patents globally. Furthermore, the formation of an appropriate policy requires an understanding of the knowledge networks and spatial patterns across Greater Perth, as well as how it connects to regional WA and other Australian capital cities. There are also opportunities to strengthen infrastructure

and connections throughout Greater Perth to grow strategic innovation hotspots and brokering hubs, supporting WA State objectives for greater economic decentralisation away from Perth city centre. This call to action is particularly pertinent given our observations of an inverse relationship between Perth's economic wealth and patenting activity, and the fact that we are predicted to be heading towards another resource upswing.

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About FACTBase

FACTBase is a collaborative research project between the Committee for Perth and The University of Western Australia. It aims to benchmark the liveability of Perth and its global connectedness through an examination of Perth's economic, social, demographic and political character.

The FACTBase team of academics and researchers condense a plethora of existing information and databases on the major themes, map what is happening in Perth in pictures as well as words, and examine how Perth compares with, and connects to, other cities around the world.

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Martinus, K., & Bo, G. (2019).
Perth's Innovation Hotspots and Collaborations,
FACTBase Bulletin 68,
The University of Western
Australia and the Committee
for Perth, Perth.

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