Firm evolution and cluster specialization: a social network analysis of resource industry change in two Australian cities

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ABSTRACT
Evolutionary perspectives have been increasingly applied to understanding industry agglomeration. By tracking change over time, evolutionary perspectives shed a light on firm-level and sectoral changes that are contextualized within global industrial shifts. This paper addresses a research gap in evolutionary economic geography and regional science by applying network dynamics of industrial agglomeration though industry- rather than firm-level relations. It uses network analysis techniques to track the evolution of two industry agglomerations between 1993 and 2015. It focuses on the resource agglomerations in Brisbane and Perth, Australia, to evaluate changes that occurred over the period of the most recent commodities-driven economic boom period. By highlighting changes in forward- and backward- linkages within firms in resource economy agglomerations, it unpacks the shifting position of core industries in inter-industry networks. Results indicate that firms either consolidated around competencies or broadened towards greater flexibility, the extent depending on the local environment. Professional services and specific resource-related activities gained centrality, while manufacturing and various intermediary services such as transportation and warehousing lost centrality. This indicates that core competencies were built around key resource sectors (notably oil and gas), while companies ‘shed’ activities that were beyond their core competencies, particularly those that could be outsourced to outside firms. This paper ultimately proposes a novel way of tracking the evolution of industry agglomeration, and by focusing on the resource industry it provides insight beyond other studies focusing on manufacturing or services.

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INTRODUCTION
Industry agglomeration is one of the most studied topics in regional science and economic geography (cf. Malmberg, Solvell, & Zander, 1996). Distinguished from urban agglomeration...
which views cities as functional outcomes of interrelated economic processes – industry agglomeration focuses on understanding how and why firms cluster within related sectors. The phenomenon can be observed from very low-level clustering (Hotelling, 1929) to regional or national levels (Malmberg & Maskell, 1997), being studied largely across the manufacturing (Carlino, 1982), services (Amin & Thrift, 1992) and high-technology (Saxenian, 1994) industry sectors over the past three decades.

Understanding the reasons behind firm clustering at the local sub-city level against the backdrop of industry agglomerations across a city or region has been a fundamental concern of scholars interested in competitiveness (Porter, 1998), innovation (Ter Wal & Boschma, 2009) and the effect(s) of regional development policy. Evolutionary economics literature on agglomeration has focused on understanding the co-constructed processes of industrial specialization and firm evolution (Cainelli, 2008; Maskell & Malmberg, 2007). On the one hand, endogenous growth theory suggests that human capital and innovation lead to the evolution of clusters (Martin & Sunley, 1998), with firms acting in the context of a local milieu. Path dependence and lock-in shape cluster specialization, the evolution of which is contingent upon new knowledge and innovation. On the other hand, macro-theories invoking the various facets of globalization assert that exogenous factors exert pressure on clustered firms, leading them to make strategic decisions in their own best interest. Changes at the global scale associated with neoliberalization and ‘new regionalism’ have hollowed out the state, privileging regional-scale actors, and firms within them (MacLeod, 2001). This has strengthened the role of the firm in shaping a city’s industry specialization and evolution (Scott & Storper, 2003). This ‘Darwinist’ perspective of a city attributes firm competitive advantage principally to its continuous specialization over time, as the vertically integrated firm of the mid-20th century specializes in goods or service provision being embedded within highly complex transborder global production networks (Henderson, Dicken, Hess, Coe, & Yeung, 2002) or global value chains (Gereffi, Humphrey, & Sturgeon, 2005).

This paper applies social network analysis (SNA) to trace the change in the two resource-based economies of Brisbane and Perth between 1993 and 2015 to understand better how clusters evolve as firm competitiveness and specialization adapts as an industry agglomerates within a city. It investigates how the structure of the two cities’ resources sectors changed in terms of direct as well as indirect activity linkages measured at the intra-firm level. It finds that shifting commodity prices and global demand had slightly different effects on the two economies as more established metals industries (e.g., gold, iron ore, copper) gave way to coal, natural gas and offshore oil industries. Firm response to these external pressures, as well as various facets of local agglomeration such as access to labour markets, resources and suppliers, firm internal restructuring and specialization, generated changes in the up- and downstream processes of each city.

ECONOMIES OF AGGLOMERATION FROM A REGIONAL PERSPECTIVE

The process of industrial agglomeration and clustering in cities is one of the most widely researched, and perhaps most often misunderstood, topics in economic geography. This research has primarily adopted a normative approach regarding how regional-level industry agglomeration is conceptualized and how it is to be studied (cf. Gordon & McCann, 2000; Malmberg & Maskell, 2002; Martin & Sunley, 2003). Despite increasingly nuanced research on clusters such as on industry-related interdependencies (Delgado, Porter, & Stern, 2016; Vincente, 2018), there remains limited exploration into how firms’ internal restructuring of operations and competencies might reflect shifts in industry agglomeration at the city level. This is largely due to a conflation by economic geography scholars regarding the multifarious complexities of agglomeration and/or clustering.

Indeed, a number of major bulwarks exist to a common understanding of what agglomeration is, how it functions in diverse contexts and how it is defined. The first issue is terminological.
As Gordon and McCann (2000) observe, a number of interrelated terms including 'agglomeration', 'clusters', 'complex', 'embeddedness', 'milieu' and 'new industrial areas' are applied 'more or less inter-changeably' (p. 515). Moreover, as Yeung (2005) confirms, economic geographers have applied several interrelated concepts such as 'institutional thickness', 'learning regions', 'local buzz' and 'untraded interdependencies' to explain the relational assets of regions. Thus, although there is recognition that various externalities shape an agglomeration, the mechanisms by which this happens are not clear. Further compounding this is terminological discord between disciplines. Clusters, for example, have very discrete spatial meaning in geography, while 'embeddedness' in sociology is associated with both Polynesian substantivism (Gemici, 2008) and Granovetter's (1985) more structuralist approaches.

A second issue is scalar. On one level, this refers to geographical scale, with 'the region' often designated as the privileged scale (Storper, 1995). There are also ambiguities around temporal scale. As Malmberg et al. (1996) note, change over time is explained alternatively as related to 'cumulative causation', 'new industrial spaces' and 'path dependence'. While cumulative causation has its origins in the political economy approaches of the early 20th century (Myrdal, 1957), the latter two are more tied to the New Economic Geography (Scott, 1988), and in Evolutionary Economic Geography (Boschma & Martin, 2007; Martin & Sunley, 2006), respectively. Though all three are widely applied, and regarded as strong theoretical bases in the study of economic agglomeration, there is variation in the degree to which temporal dynamics are important, and whether they affect firms or the broader milieux.

The third issue is methodological, as there is little agreement on how to operationalize research on agglomeration. As Gordon and McCann (2000) assert, this is exacerbated by the fact that none of the current approaches is particularly adept at measuring change over time. Overall, studies in industry agglomeration have been approached from many perspectives. Among these are static spatial analysis using location quotients or shift–share analysis of industry concentration or specialization (O’Donoghue & Gleave, 2004; Polèse & Shearmur, 2006), and input–output modelling of regional competitiveness and/or productivity (Titze, Brachert, & Kubis, 2011). Others examine relational aspects focusing on firm or industry interdependencies and regional innovation or production systems applying methods such as SNA (Giuliani, 2007), econometric or regression modelling (Raspe & van Oort, 2011) and qualitative studies (Rutherford & Holmes, 2008; Shin & Hassink, 2011).

Fourth, and finally, the role of the firm differs from one perspective on agglomeration to the next. New institutionalist perspectives focus on the role of governmental frameworks, while neoclassical theorists place more emphasis on the firm and its internal mechanisms. Within much of this literature, however, firms are treated as homogenous (Ottaviano, 2010). Though this assumption is partly due to difficulty in gathering accurate information on firm activities or the way economic activities are classified, it also points to a lack of knowledge about how forward and backward industry linkages are embedded within ‘core’ driving industries. Another deficiency of this work concerns the measurement of interactions between firms and industries. While multipliers and spillovers are assumed (Bathelt, 2007), and often built into econometric models, there is limited investigation of the complexity of intersectoral relations embodied within firms.

This paper seeks to address the latter two issues by applying network analysis to cluster specialization as a function of firm evolution. Network analysis has recently made inroads into economic geography and regional science (cf. Cassi, Morrison, & Ter Wal, 2012; Glückler & Doreian, 2016), but is still evolving as a method. Though network analysis does not explain the causality inferred by direct relations, one of its primary advantages is that it allows for both direct and indirect linkages to emerge as part of an economic system. This also allows for an understanding of how industrial activities are organized and interrelated through intra-firm–level backward linkages to suppliers, forward linkages to producers, as well as the range of services provided within firms, partners and contractors. Intra-firm relations add to the
deep knowledge base regarding interaction between firms and industries that has traditionally been dominated by input–output analysis (O’Donoghue & Gleave, 2004). Given that the resource sector is more complex than many others due to the geographical diversity of producers and consumers, the analysis of second-order relations is critical to understanding the full range of networked relations between industries. The following section address this through a network analysis of the resource cities of Perth and Brisbane.

**URBAN DIVERSIFICATION FROM SIMPLE RESOURCE EXTRACTION: PERTH AND BRISBANE**

In contrast to the many other studies on industry agglomeration in information technology or manufacturing (Polèse & Shearmur, 2006; Saxenian, 1994), we focus on the resources sector. Though individual sectors have been researched using similar methods (Atienza, Luñín, & Soto, 2018), the dynamics of cities’ entire resource economies have not been studied in great detail. The fundamental contribution of resources to the global economy makes their corporate production networks complex, extending from extraction sites in often peripheral locations to trading and transport hubs, centres of trade, and distribution nodes (Martinus, Sigler, Searle, & Tonts, 2015). Resource firms tend to have complex ownership arrangements and resource-extraction rights, as well as be highly interdependent with other industry sectors such as logistics, construction and business services (Dicken, 2011). These multifarious requirements drive the strong agglomeration tendencies of the sector in resource-based economies (Bridge, 2008). Importantly, the national security importance of resources as well as sale of mining rights implies that the state is often heavily influential in the development of the resource sector, particularly energy (e.g., Petrobras, Petronas, Saudi Aramco) (Labban, 2011). As a result, resource companies tend to locate corporate offices in core metropolitan areas where, inter alia, they can gain easy access to key political and business decision-makers in resource economies (cf. Sigler, Searle, & Martinus, 2018).

Local backward linkages are facilitated by connecting multinational resource companies to local firms, while forward linkages are tied to refinement and advanced production. These are distinguished by their respective sequence along production processes: upstream (supplier) relations such as machinery provision indicate backward linkages, while downstream (consumer) relations such as metal fabrication denote forward linkages. As the resources sectors have evolved beyond extraction toward the coordination of complex production processes involving intermediate and finished products, backward and forward linkages become contingent on greater levels of technology and sophistication.

The complex network relations of industries can be illustrated by using the Australian cities of Perth and Brisbane to unpack how contemporary industry agglomeration morphs over time. Perth is the business hub and state capital of the resource-rich state of Western Australia (WA), which produces oil, gas, iron ore, nickel, alumina, copper, zinc and gold, as well as large proportions of global production of diamonds, zircon and garnet. The state’s mineral and petroleum industries comprised nearly half of total national exports in 2014. These activities are widely distributed over the state’s vast territory, with oil and gas production on- and offshore in the north-west, iron ore production in the state’s north-west Pilbara region, and nickel, copper and gold primarily in the south and south-east of the state.

Brisbane occupies a very similar role within the state of Queensland. Coal and coal seam gas are found in the state’s inland basins, with large deposits of copper and base metals to the north-west, bauxite to the north on Cape York Peninsula and precious metals to the east along the coast. In 2015–16, Queensland accounted for 21% of national total merchandise exports, with mining and petroleum accounting for more than half that, and coal being the largest category.

**REGIONAL STUDIES, REGIONAL SCIENCE**
(Australian Bureau of Statistics (ABS), 2017). The two cities are the fourth and third most populous in the country, respectively.

DATA

Data on resource sector and related Brisbane and Perth firms were gathered from two related compendia of Australian businesses published annually. The 1993–2015 interval chosen for this study corresponds to the end of the two most recent Australian resources booms. The majority of economic gains from such booms (e.g., employment, population and disposal income) tend to accrue largely in the resource states (notably WA and Queensland) as well as in the resource-related sectors of the wider economy, with other sectors impacted by higher exchange rates and interest rates (Garton, 2008).

The study period is also contextualized by globally scaled economic processes that had a fundamental influence on the Australian economy. Neoliberal policies expanded and increased priority was given to economic growth and attracting private investment. Associated with this was the increased use of private capital in public projects through public–private partnerships. Trade liberalization continued apace. The economic rise of China and its capture of a bigger share of global trade was accompanied by industrial decline in the Global North, though services based on information technology grew globally. In Australia, these global shifts were reflected in growing resource exports to China and contraction of domestic manufacturing especially in non-mining states. This meant increasing redirection of capital investment to WA and Queensland through Perth and Brisbane. Backward linkages by resource companies to domestic manufacturers atrophied, but linkages with advanced services strengthened where these provided competitive advantages.

Changes in the structure of Australia’s mining and energy resources sector during the study period show, first, a rapid acceleration in project development from around 2005–06, with the value of major projects increasing from under A$50 billion annually before 2007 to over A$200 billion annually by 2011 at the peak of the boom (Bureau of Resources and Energy Economics, 2012). Second, they show a change in the structure of the sector over the period. After 2007, energy developments were dominant, while infrastructure projects also became increasingly important. These trends meant that by the end of the study period, linkages within the Perth and Brisbane resources sectors were underpinned by a rapid recent increase in demand that was now much more skewed to energy (offshore gas in Perth and coal and gas in Brisbane) and infrastructure than at the start of the study period.

Data for 1993 were extracted from the 1993–94 Kompass Australia business directory (Isaacson Publications, 1994). This contained listings of each type of good or service supplied by Australian firms, with firms classified by office address (including branches) and a five-digit subsector category. The equivalent 2015 directory, B2B Australia, was accessed online (http://australianb2b.com.au/australian-b2b/About-Kompass.aspx), and included a total of 47,685 Australian businesses and institutions listed. Published by JPM media, B2B Australia is arguably the most comprehensive directory of its kind, with records on individual firms indicating a variety of data including registration number, address, financial turnover, year of establishment, related brands and product summary. Like the 1993–94 directory, it also includes five-digit product codes detailing the range of goods and/or services offered.

Resource production firms were easily identified, such as in natural gases or ores and heavy metals. Upstream (backward) and downstream (forward) linkages to resource production were also included. The former included firms involved in resource extraction-related construction, drilling, excavation and related provisioning (e.g., offshore and underwater work contractors; mining and quarrying machinery and equipment); and the latter included firms in resource processing and transportation industries, such as materials management (logistics) consultants and...
materials testing and assaying, where at least one product/service form the firm was associated with the resources sector by having ‘exploration’, ‘mining’ or similar in the product description. This included specialized firms (such as in engineering or aviation) likely servicing clients across many industry sectors. As such, the final 1993 and 2015 product and service category lists of firm activities represented temporal snapshots of resource-related firm agglomeration in the two cities.

For 2015, 889 relevant firms in the Brisbane or Perth greater capital city statistical areas across 93 product or service categories relating to resources production and related services were analyzed. Some concordance was done to harmonize 1993 and 2015 data as the codes were marginally different for the two years. As with the 1993–94 directory data, B2B codes associated with these categories were chosen based on the researchers’ judgment, referencing literature on resource-related industries (Rayner & Bishop, 2013).

Given the desire to model intra-firm industry sector relations, the final list of 628 product or service categories in 1993, and 564 in 2015, was reduced through reclassification to allow higher level specializations to emerge. Analysis was performed at three scales: product/service subsectors, industries and activities, each of which represents a step of aggregation to rationalize the number of nodes and the size of the overall network(s) (Table 1). Though Kompass/B2B directories use a ‘proprietary’ five-digit listing, this reclassification was done broadly to harmonize categories with commonly used scales of analyses as per taxonomies such as the North American Industry Classification System (NAICS) or the Global Industry Classification System (GICS). Firms were included if they supplied goods or services in any of the five-digit subsectors listed in Appendix A in the supplemental data online.

**METHODOLOGY**

SNA was applied to analyze firm networks for both years. A derivative of graph theory, SNA was initially conceived of to understand interpersonal relations (Scott, 2017); as such is it an appropriate method to use for understanding firm interdependencies. SNA is a type of network analysis consisting of nodes and ties. It allows for the analysis of the entire network, sub-networks (i.e., parts of the whole) or of the network of individual nodes, known as ego-networks. It also provides metrics pertaining to two- or three-way relations, known as dyads and triads, and to individual nodes. Though network analysis may have been a peripheral research tool in the recent past, a number of studies have incorporated it into studies on urban agglomeration and ‘global cities’ (Sigler, 2016), innovation (Huggins & Prokop, 2017), embeddedness (Fletcher & Barrett, 2016), and evolutionary economic geography (Cassi et al., 2012; Glückler, 2007). The application of network analysis has thus become increasingly prevalent, reflecting a broader tendency toward relational perspectives (Grabher, 2006).

Though input–output analysis is another useful approach to tracking industry evolution (Titze et al., 2011), we argue that network analysis holds several distinct advantages in this

|                      | Perth, 1993 | Perth, 2015 | Brisbane, 1993 | Brisbane, 2015 |
|----------------------|-------------|-------------|----------------|----------------|
| Firms                | 161         | 252         | 121            | 230            |
| Subsectors           | 628         | 416         | 492            | 387            |
| Industries (aggregations of subsectors) | 57 | 51 | 54 | 47 |
| Activities (aggregations of activities) | 6 | 6 | 6 | 6 |
| Sum of all connections | 21,098 | 1797 | 19,200 | 2015 |
First, network analysis allows for the quantification and identification of both direct and indirect linkages. Ties indicate linkages between firms and industries, while centrality allows one to understand positionality as a function of transitive relations.

Second, network analysis allows for an understanding of the position of individual industries as nodes, or for an understanding of entire networks or sub-networks. In this case, we look to networks at alternating scales (e.g., macro-industries, industries) to view changes over time (Glückler & Doreian, 2016).

Third, networks have been identified as particularly useful in evolutionary research. As Fletcher and Barrett (2016) assert, they allow one ‘to study the evolution of such relationships between the major actors over time – how relationships are formed, maintained, and broken’ (p. 572). Glückler and Doreian (2016) add that this approach yields an understanding of the ‘relationship between the spatial evolution of networks and the imprint of network dynamics on the development of places and regions by considering endogenous change and the concept of network trajectories’ (p. 1127).

Fourth, an evolving set of tools and applications within network analysis allows this study to be benchmarked against other recent literature. Furthermore, intra-organizational ties have clear boundaries so that no artificial limits need to be delineated (Bergenholtz & Waldstrøm, 2011).

The SNA program NodeXL was used to compute the matrix relationships between categories through various centrality measures and dyadic relationships. Though the primary focus of the analysis was by industry, finer trends from the subsector analysis and coarser trends from the activity analysis were also considered. This multiscalar analysis allowed for relationships to be understood at various levels of aggregation. In the analysis, ‘ties’ between industries resulted from within-firm relations, as the majority of firms traded in more than one product or service. In other words, if a firm listed Category 01234 and Category 56789 as core economic functions, a tie between the two was assumed. The complete set of relationships in each city for each year yielded four initial two-mode firm by industry sector category matrices: two of the 161 Perth firms in 1993 and 217 in 2015, and two of the 121 Brisbane firms in 1993 and 200 in 2015. These two-mode matrices were converted to four one-mode category-by-category symmetric matrices, where a 1 was placed into the corresponding cells of each product or service category offered by an individual firm listed down the first column by all other categories offered by the firm listed along the top row (Figure 1). Industries were listed as connected to themselves only if firms only listed a single subsector (e.g., industry 2 connected to itself for firm B in Figure 1), and ties were recorded only once, meaning that b-a was recorded as a-b.

The number in each a-b category-pair cell was the sum of all firms trading in that particular category-pair product or service. Thus, each cell contains the total number of intra-firm linkages between industry a and industry b in each city.

A series of metrics were extracted from the network graph, including eigenvector centrality (EC) and betweenness centrality (BC). While EC indicates the degree of node power by measuring its direct connections to other well-connected nodes, BC reflects the degree to which a node acts as a broker or bridge between two other nodes. Though many centralities exist, EC and BC are complementary, with EC measuring the value of a node in the overall global network and BC in its local network (Sigler & Martinus, 2016). Additionally, dyad analysis was applied to examine relevant industry sector pairs, revealing which subsectors were most likely to be both performed within firms.

The overall networks revealed the cumulative sum of the connections between subsectors by city and year. Centrality measures and dyads emerged from the overall network, indicating the degree to which industry sectors formed part of the core, or periphery, of the overall network and their prominence in bilateral relations. In order to focus on the evolution of resource-based industry in Perth and Brisbane, change over time was a key focus of the analysis. This involved taking the normalized values for BC, EC and dyads in 1993 and computing change...
against the same measure for 2015. While static measures are perhaps best for interpreting individual graphs, the dynamic measures of change were considered better suited to analyze structural change in each city’s resource agglomeration over time.

The change in BC across the two periods denoted a change in which sectors were acting as a bridge between other sectors – the greater the change, the more important that sector had become within the firm as a core competency given it linked other sectors. For example, the sector ‘tools and accessories’ may be the key link between a group of related sectors centred around manufacturing and production. This would be because all other sectors in this group require ‘tools and accessories’, and therefore is frequently a core activity in firms. Similarly, the change in EC across the two periods denoted a change in which sectors were more strategically linked to the most important sectors – the greater the change, the more important that sector had become within the firm as a core strategic competency. For example, the ‘manufacturing/basic metals’ sector may be the most strategically linked sector between the same variety of related sectors centred around manufacturing and production. This would be because the most connected sectors (to other sectors within a firm) in this group are also connected to ‘manufacturing/basic metals’, denoting it is a core sector to firm operations. These changes occurred as firm activities changed between the periods being either outsourced, shed or brought into mainstream production, as such there was a general shift in the internal structure of firms.

**STRUCTURAL CHANGE OF PERTH AND BRISBANE RESOURCE ECONOMIES**

An analysis of cluster specialization as firms evolved in Perth and Brisbane between the study years of the 22-year interval was conducted. In both cities, while increases over time in the number of firms were matched with decreases in product or service subcategories, there was an inverse trend in industry sectoral specializations. More specifically, firms in Perth moved from a broader palate of resource production, manufacturing supplies, commercial services, and building and

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**Figure 1.** Conversion of two-mode (firm-by-industry) matrix to one mode (industry-by-industry).
public works in 1993 to a greater focus on manufacturing supplies and building and public works in 2015 (Figure 2). Firms in Brisbane expanded from a primarily manufacturing supply specialization in 1993 to include other industry sectors of building and public and commercial services in 2015 (Figure 3). In Figures 2 and 3, the size of nodes is determined by BC, and this can be linked to the different nature and drivers of each city’s economies.

As the graphs show, Perth’s resources agglomeration was dominated by equipment, tools and accessories tied to extractive industries. In particular, electrical services, metal industry products, wholesale distribution and equipment for building, mining, transport, hydraulic, pneumatic, heating and cooling were the most central to Perth’s 1993 network. By 2015, this has changed slightly – equipment of various sorts was still central to the agglomeration, but contractors gained a central role, especially in mechanical engineering, oil and gas, mineral prospecting, and building.

Figure 2. Network of industry sectors in Perth, 1993 and 2015.
Brisbane’s 1993 network was similar to Perth’s to some degree, with electrical, chemical processing, building and handling equipment at its core, complemented by commercial services and metal industry products. The 2015 network reflects an increasing role for consultants and contractors in engineering, growth in specialized services such as research, testing and public administration, and a less central role for metals in favour of oil and gas. Industries closer to the centre of Figures 2 and 3 are core to each network, as are those appearing as larger nodes.

**Industry sector dyad analysis**

Dyads are the primary bilateral relations within a network, in this case representing pairs of subsectors that are components of firm activity. Dyads indicate which industries are highly linked to one another across firms. Tables 2 and 3 indicate changes in industry dyads over the 22 years in Perth and Brisbane. An increase in these bilateral industry sector ties indicates many firms in Perth enhanced their capabilities in oil and gas and related industries such as chemical industries.
Table 2. Top increases in dyadic relationships, 1993–2015 (percentage change in relative ratio).

| Perth | Brisbane |
|-------|----------|
| General mechanical engineering contractors ↔ Commercial services – other (0.79) | Information technology hardware and software ↔ Mining and extraction equipment (0.98) |
| Sea transportation ↔ Commercial services – other (0.63) | Consumer products – personal and miscellaneous items ↔ Civil engineering (0.93) |
| Crude oil and gas ↔ Chemical and oil industries (0.52) | Civil engineering ↔ Oil, gas and mineral prospecting contractors (0.86) |
| Civil engineering ↔ Oil, gas and mineral prospecting contractors (0.51) | Consumer products – personal and miscellaneous items ↔ Wholesale distribution: general equipment and supplies (0.65) |
| Non metallic minerals ↔ Building contractors and related services (0.48) | Minerals – metals ↔ Basic metal industries (0.65) |
| Precision equipment ↔ General mechanical engineering contractors (0.47) | General research, analysis, testing and related services (0.62) |
| Oil, gas and mineral prospecting contractors ↔ Building contractors and related services (0.44) | Consumer products – personal and miscellaneous items ↔ Engineering and related consultants (0.61) |
| Rubber and plastic products ↔ Transport equipment (0.43) | Engineering and related consultants ↔ Public administration and services (0.56) |
| General mechanical engineering contractors ↔ Civil engineering (0.43) | Chemical production and processing equipment ↔ Consumer products – personal and miscellaneous items (0.51) |
| Chemical and oil industries ↔ Building contractors and related services (0.38) | Heavy industry machinery and equipment ↔ General mechanical engineering contractors (0.48) |

Table 3. Top decreases in dyadic relationships, 1993–2015 (percentage change in relative ratio).

| Perth | Brisbane |
|-------|----------|
| Rubber and plastic products ↔ Chemical and oil industries (~0.99) | Chemical and oil industries ↔ Chemical production and processing equipment (~0.96) |
| Textile ↔ Chemical and oil industries (~0.98) | Metal industry products – building ↔ Building and handling equipment (~0.92) |
| Rubber and plastic products ↔ Information technology hardware and software (~0.88) | Chemical and oil industries ↔ Basic metal industries (~0.92) |
| Paper, printing and publishing ↔ Rubber and plastic products (~0.86) | Precision equipment ↔ Commercial services – other (~0.92) |
| Wholesale distribution: consumer goods ↔ Wholesale distribution: general equipment and supplies (~0.81) | Metal industry products – building ↔ Transport equipment (~0.88) |
| Metal industry products – building ↔ Engineering and related consultants (~0.8) | Metal industry products – building ↔ Hydraulic, pneumatic, heating and cooling equipment (~0.86) |
| Chemical and oil industries ↔ Precision equipment (~0.78) | Metal industry products – tools, accessories ↔ Hydraulic, pneumatic, heating and cooling equipment (~0.84) |
| Textile ↔ Mining and extraction equipment (~0.78) | Management consultants ↔ Engineering and related consultants (~0.81) |
| Building and handling equipment ↔ Heavy industry machinery and equipment (~0.77) | Transportation: agents and storage ↔ Engineering and related consultants (~0.8) |
| Building contractors and related services ↔ Engineering and related consultants (~0.76) | Basic metal industries ↔ General mechanical engineering contractors (~0.78) |
and prospecting contractors. Also significant was an increase in non-prospecting contracting, particularly engineering contractors and building contractors. This indicates a greater co-incidence of contracting services that sit in-house alongside commercial and engineering services, as well as precision equipment in, for example, specialized metal fabricators and engineering outfits.

Brisbane had a similar trend as more contracting services pair with engineering, research and testing, and heavy industry machinery and equipment. The top dyad increase of information technology, hardware and software with mining and extraction equipment is indicative of the greater role of technology in mining. This reflects the increasing knowledge-intensive concentration in the city and sophistication of resource extraction.

Decreases in industry sector dyads are shown in Table 3, indicating where two activities were increasingly less interdependent. Again, the two cities were similar in some ways and different in others. Perth had a loss of industry sector activities such as textiles, rubber and plastic products, and paper, printing and publishing. The data included distributors as well as producers of each product or service, but the 1993–2015 dyad changes nevertheless indicate a decline in supply outlets in these activities. This could suggest increased specialization by chemical and oil companies, for example, servicing the construction contracts of large mining companies such as BHP and Rio Tinto in 2015. These contracts may have meant greater use of major contractors and suppliers who globally source materials such as plastic electrical and plumbing components, compared with the greater use of local suppliers by small gold companies in 1993. The decline in the wholesale dyad similarly suggests increased specialization and direct global sourcing, as does a loss in ties between equipment-related industries within firms, including precision equipment and heavy industry machinery and equipment.

Technological change was also a factor. For example, as companies specialized in the supply of new technologies, such as in durable mining equipment exemplified by development of the Tomcar light underground mining vehicle (Austmine, 2015). The use of electronic communication by mining companies by 2015 would have reduced demand for paper, printing and publishing.

Brisbane had a similar loss in industry sector ties to chemical production and processing equipment; transport equipment; and hydraulic, pneumatic, heating and cooling equipment. However, unlike Perth, there was a decoupling of services and consultants, as well as various elements of the metals industry, from resource firm activities. This indicates growth in more specialized firms servicing new major project starts compared with 1993, evidenced by new firms such as Industrial Control and Electrical, which supplies electrical conveying systems and electrolytic metal smelting infrastructure (Industrial Control and Electrical, 2017).

There are several possible explanations for decreases in dyadic relations. First, one or both industries were ‘shut’ by firms with a lower strategic advantage from being maintained in-house. For example, at the end of the study period, major Perth mining services company Ausdrill outsourced its transport business and sold two of its manufacturing businesses (Ausdrill, 2016), while multinational Anglo American ofload its non-core assets (Australian Mining, 2016).

Second, more specialized firms increasingly dominated certain industrial functions, in the form of either small highly specialized firms or very large (and likely multinational) firms whose economies of scale out-competed benefits of keeping the industry in-house. An example is Perth firm Minnovare, established in 2012, that provides autonomous drill rig alignment technology which increases drilling accuracy and reduces drilling time (CSIRO Futures, 2017).

Third, mergers to achieve economies of scale led to rationalization of product offerings. While the data cannot indicate what was at work in any given case, we can infer this from broader industrial trends and from specific company activities, as evinced in the above examples and
others such as the takeover of Brisbane mining equipment company Industrea by General Electric in 2012.

**Industry sector specialization and urban agglomeration**

In Perth and Brisbane, the effects of deindustrialization have been mitigated by growth in resources-related services and the strength of commodity prices linked to the local mining and energy industries.

Table 4 indicates change in EC over time. Perth saw an increase in the importance of contractors – general mechanical engineering contractors, and oil, gas and mineral prospecting contractors. The rise of major Perth-based firms in this sector such as Woodside was directly linked to resource investments throughout WA. Other advanced services, such as market research, advertisement and drawing services, and civil engineering also increased, as did various ancillary categories such as building maintenance, and leasing and renting. This was countered by declines in wholesale distribution and importing, mainly of machinery and raw materials, as well as in information technology, hardware and software, and general research, analysis, testing and related services, which were most likely outsourced to specialized firms. The rise of new and expanded specialist Australian mining services companies using advanced software and related

**Table 4. Eigenvector centrality change, 1993–2015.**

| Increases | Decreases |
|-----------|-----------|
| **Perth** | **Brisbane** | **Perth** | **Brisbane** |
| General mechanical engineering contractors | Public administration and services (0.84) | Wholesale distribution: base materials (–0.73) | Commercial services – other (–0.53) |
| Building maintenance (0.38) | Oil, gas and mineral prospecting contractors (0.67) | General research, analysis, testing and related services (–0.53) | Transportation: agents and storage (–0.51) |
| Sea transportation (0.37) | Consumer products – personal and miscellaneous items (0.5) | Minerals – non-metal (–0.35) | Wholesale distribution: base materials (–0.44) |
| Market research, advertisement and drawing services (0.35) | Minerals – metals (0.37) | Non-metallic mineral processing equipment (–0.34) | Leasing and renting (–0.41) |
| Leasing and renting (0.3) | General mechanical engineering contractors (0.33) | Importers (–0.3) | Heavy industry machinery and equipment (–0.41) |
| Oil, gas and mineral prospecting contractors (0.3) | Information technology hardware and software (0.25) | Engineering and related consultants (–0.29) | Building and handling equipment (–0.39) |
| Consumer products – personal and miscellaneous items (0.28) | General research, analysis, testing and related services (0.25) | Wholesale distribution: consumer goods (–0.27) | Rubber and plastic products (–0.29) |
| Civil engineering (0.21) | Hydraulic, pneumatic, heating and cooling equipment (0.16) | Commercial services – other (–0.27) | Minerals – quarrying (–0.28) |
| Non metallic minerals (0.18) | Business associations (0.14) | Information technology hardware and software (–0.26) | Metal industry products – building (–0.27) |
| Crude oil and gas (0.17) | Textile (0.14) | Minerals – other (–0.26) | Sea transportation (–0.27) |
technology over the study period (Australian Trade Commission, 2013; CSIRO Futures, 2017) indicates this trend. By contrast, the 38 firms in importing were the highest number in industries with major EC declines.

Brisbane saw an increase in professional services, particularly in public administration and services; general research, analysis, testing and related services; and business associations, which includes, for example, the quality control organizations subsector. Oil, gas and mineral prospecting also increased in EC through companies such as IOR Energy and GHD – a global services firm with large Queensland operations. The rise of the coal seam gas industry post-2000 generated demand for a new range of professional services due to the geospatial dispersion of its activities, necessitating new types of specialized infrastructure such as gas wells and pipelines and activities relating to gas testing, community engagement and landowner compensation (Thomas, 2015). Conversely, Brisbane decreases were primarily related to manufacturing, such as rubber and plastic products, and heavy industry machinery and equipment. The coal seam gas industry did not have the same need for the latter as did the coal industry in earlier years. By 2015, there was a glut of rented mobile mining equipment (GraysOnline, 2015): leasing and renting thus experienced a significant decline in EC from 1993, when there were eight such firms. The findings indicate overall that as specialized services became integral to corporate activities, many other activities such as transport, wholesaling and heavy industry became less connected.

Table 5. Betweenness centrality change, 1993–2015.

| Increases                                      | Decreases                                      |
|-----------------------------------------------|-----------------------------------------------|
| Perth                                         | Brisbane                                      | Perth                                         | Brisbane                                      |
| Sea transportation (0.65)                     | Consumer products – personal and miscellaneous items (0.79) | General research, analysis, testing and related services (–0.7) | Leasing and renting (–0.94)                   |
| Financial services (0.5)                      | Public administration and services (0.75)      | Engineering and related consultants (–0.56)    | Management consultants (–0.65)                |
| Chemical production and processing equipment (0.39) | Minerals – metals (0.56)                      | Management consultants (–0.56)                | Wholesale distribution: base materials (–0.63) |
| General mechanical engineering contractors (0.29) | Textiles (0.51)                               | Importers (–0.52)                             | Commercial services – other – other (–0.59)    |
| Rubber and plastic products (0.26)            | General mechanical engineering contractors (0.5) | Wholesale distribution: base materials (–0.48) | Transportation: agents and storage (–0.49)    |
| Building maintenance (0.22)                   | Minerals – quarrying (0.47)                   | Textiles (–0.42)                              | Building and handling equipment (–0.44)       |
| Market research, advertisement and drawing services (0.2) | Information technology hardware and software (0.4) | Non-metallic mineral processing equipment (–0.41) | Agricultural and forestry (–0.43)             |
| Oil, gas and mineral prospecting contractors (0.19) | Transport equipment (0.37)                   | Heavy industry machinery and equipment (–0.31) | Rubber and plastic products (–0.38)           |
| Wholesale distribution: consumer goods (0.15) | Building contractors and related services (0.23) | Mining and extraction equipment (–0.29)       | Chemical production and processing equipment (–0.36) |
| Non metallic minerals (0.13)                  | Agricultural and food equipment (0.21)         | Metal industry products – building (–0.29)     | Heavy industry machinery and equipment (–0.35) |

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In contrast to EC, BC indicates industries that act as bridges to other industries, having the largest effect on connecting the network as a whole if removed from the network (Scott, 2017). Changes in BC in each city are shown in Table 5. In Perth, a broad range of industries assumes greater BC, including services (financial services; sea transportation; market research, advertisement and drawing services) and contractors (oil, gas and minerals; general mechanical engineering). This is explained by general increases in sectors (transport, contracting, engineering; oil and gas) to which these specific industries are interrelated. The need for specialized services can also be attributed to the strong demand for WA minerals, in particular iron ore and gold as world prices peaked. In addition, increasing BC of these industries is also associated with the rise in production equipment needed during the construction phase of the stronger post-2000 resource boom and in the construction of several large mining and oil and gas projects such as Gorgon, Wheatstone, Hamersley Iron and Hope Downs. Overall, the increases signify the impacts of the WA resources boom where an increasing supply of goods and services was needed to facilitate the expansion of resource production.

A variety of less-specialized services decreased in BC, including importers and wholesale distribution, as well as manufacturing-related industries such as textiles and heavy industry machinery and equipment. As the textile industry sector includes belts, hoses, canvas and ribbons, it represents the sort of resource-related manufacturing that has either been outsourced to more specialized firms or offshored. The dominance of large resources companies, in particular BHP-Billiton, Rio Tinto and Woodside, in WA’s resource economy was reflected in categories with the largest decreases, such as management consultants (32 firms in 1993), as these activities would be carried out in-house.

Brisbane had an inverse pattern. Textiles, transportation equipment, and agricultural and food equipment increased in BC, indicating continued diversification of the Queensland resource economy, as these industries provided links to ancillary products and services. Further, increases in public administration and services, and information technology, hardware and software, indicates enhanced diversification and sophistication in companies such as Fugro – a global engineering firm with its major Australian presence split between Brisbane and Perth.

Three broad categories of industries lost network importance in Brisbane as measured by BC. These included consultants (its 28 firms in 1993 being the largest number in industries with major BC declines) and distribution (comprised of transportation: agents and storage; leasing and renting; and wholesale distribution: base materials). Leasing and renting decline was most likely associated with the end of the post-2000 boom and a downturn in new projects requiring mobile construction equipment hire. As in Perth, smaller consultants were likely also contracting by 2015 due to the decline in new projects.

CONCLUSIONS

Understanding cluster specialization is vital to formulating strategies that champion the benefits of localization. This can be historically traced to the global pressures of commodity markets as well as the localization effects derived from the traded and untraded interdependencies within the cities themselves. In this instance, evolution of firms within the resource agglomerations of Perth and Brisbane provide evidence of industry interdependency changes over time, and the specialization of clusters. As firms adapted their strategies to both global pressures and local conditions, their breadth and depth across industries changed. The analysis shows the dynamic nature of firms in both cities meant an increased industry specialization over time. Perth’s greater specialization may be linked to its high resource wealth and greater historic reliance on the sector, while the lower rate of industry specialization of Brisbane may be linked to its greater economic diversity. The intra-firm level network analysis of this paper has allowed the identification of changes in both direct and indirect interdependencies. This occurred against a backdrop of
increased in-house activity by large multinational firms to leverage economies of scale and connections to global partner networks.

On a city level, Perth specialized over time with an enhanced role in core sectors of oil, gas and mining, as well as ancillary industries such as shipbuilding, chemicals, and engineering services as a result of large capital outlays on developing, supporting and servicing remote production sites. Small companies, such as Perth’s ‘junior’ miners, specialized in fewer activities, often with more technological sophistication and/or increasingly undertaking consulting and contracting roles. Brisbane also specialized, particularly around Queensland’s dominant resources industries: gas, metals, non-metallic minerals and coal. However, unlike Perth, heavy industry was not ‘shed’ but specialized around the expansion of underground gas and metal ore production requiring different infrastructure and equipment to open-cut coal mining, dominant in 1993. There was also increased sophistication and specialization by firms engaging in contracting and consulting. Firm competitive strategies evolved around strategic interdependencies between particular industries. The development of new mines and gas fields required local consultants, contractors and transportation as well as production equipment and other infrastructure (from local distributors, if not made locally). As input demand grew, supply companies established, expanded and/or specialized, with many gaining specialized knowledge and economies of scale for global expansion.

This research demonstrates that industry specialization at the city level can also be seen as an outcome of the evolving specialization of firms through the internal restructuring of operations. This supports a generalized Darwinist view regarding firm evolution and survival in increasingly competitive global markets (cf. Kogler, 2015). The approach of this paper demonstrates that firms will either absorb or abandon various economic activities to remain competitive in the resource cities of Brisbane and Perth. Moreover, though there was relatively little firm survival, the interdependencies of the cities’ respective resource companies remained relatively constant. Both globalization and localization were the ostensible drivers of this cluster specialization, emphasizing the resource agglomeration dynamics that distinguished the two cities from each other. The network approach allows this to be unpacked at both industry sector and subsector scales, with network-derived measures (e.g., centrality) indicating positionality of firms over time. Huggins and Prokop (2017) contend that this positionality influences innovation and economic development when viewed on a regional scale. The understanding of industry structure and positionality within each city emerging from the application of this network approach suggests it is an appropriate method to use for further research on cluster specialization as a function of both urbanization and localization economies.

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