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Cities as networks within networks of cities: the evolution of the city/firm-duality in the world city network, 2000-2010¹

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Abstract

We explore the temporal evolution of cities and firms (i.e. both modes) in a two-mode intercity corporate network formed by 50 leading advanced producer service firms across 154 cities for the years 2000 and 2010. Drawing upon one-mode network projection and three network centralities, we assess the shifting positions of individual cities and firms in the one-mode intercity and interfirm networks. Major findings include: (1) the intercity network is more stable and hierarchical than the interfirm network; (2) brokerage functions, as captured by betweenness centrality, remain highly uneven for both cities and firms. For example, New York and London's distinct positions as the world's leading producer service centres remain intact; and (3) regional and sectoral tendencies are evident in terms of growth rates of centralities.

Key words:

Duality; two-mode networks; intercity corporate network; temporal evolution

¹ Our title is appropriately based on Berry's (1964) classic paper, in which he emphasised that the study of cities' position in a 'system' cannot be separated from the study of what goes in within these cities. The analytical approach advanced in this paper reflects the spirit of Berry's message.

INTRODUCTION

It seems fair to state that Peter Taylor's (2001) formal specification of the 'world city network' (WCN) as an 'interlocking network' has been a milestone in the world cities literature. In this 'interlocking world city network model' (IWCNM), cities are deemed connected through the flows of information, knowledge, capital, people, etc. generated within the office networks of globalised advanced producer services (APS) firms. Drawing on this IWCNM specification and a series of concomitant data gatherings to 'feed' the model, Taylor and colleagues from the Globalisation and World Cities (GaWC) research network have provided detailed descriptions of the connectivity of cities in the WCN (e.g. Taylor et al. 2011).

Parallel to the APS analyses of the GaWC group (www.lboro.ac.uk/gawc), other approaches and strategies have been developed to study WCN formation. This includes studies of global infrastructure networks such as airline passenger networks (e.g. Smith & Timberlake 2001), maritime networks (e.g. Ducruet 2013), and Internet backbone networks (e.g. Rutherford et al. 2004), but also strategies that are more akin to the GaWC approach in that the analytical focus is on the geographies of corporate networks (e.g. Hoyler & Watson 2013; Krätke 2014; for overviews, see Liu & Derudder, 2012a; Neal, 2013). The most common approach in this regard has been empirical research that focuses on headquarter-subsidary relations within the corporate structures of multinational corporations (MNCs), for example, the work of Alderson & Beckfield (2004), Wall & van der Knaap (2011), and Rozenblat & Pumain (2007).

The particular appeal of the research drawing on Taylor's IWCNM can probably be traced back to its theoretical foundations. In a literature that had long been flawed by a combination of eclecticism and fuzziness, Taylor (2001) presented the IWCNM in the context of the well-established literature on social network analysis. In addition, the assumptions underlying the IWCNM specification were not merely asserted, but explained in the context of Sassen's (1991) research on 'global cities' and Castells' (2001) writings on 'the rise of the network society'. Nonetheless, some of the tenets of the IWCNM specification have – albeit somewhat belatedly – come under close scrutiny in recent years

(e.g. Nordlund 2004; Beckfield & Alderson 2006; Neal 2011, 2012, 2013; Hennemann & Derudder 2013). One issue that has been raised in this context, and which will also be the core focus of this paper, is that most of the research drawing on the IWCNM does not make appropriate use of all the information contained in the original datasets.

Taylor's (2001) specification of the WCN essentially starts off as a so-called 'two-mode network' or 'dual network' (Breiger 1974; Liu & Derudder 2012b). A two-mode network consists of two disjointed sets of nodes, whereby the primary data connect nodes of both sets. The starting point of GaWC's analyses are indeed two-mode networks, as the datasets consist of two disjointed sets of nodes (world cities and globalised APS firms) whereby the primary data consist of links connecting nodes of the different sets (the presence of globalised APS firms in world cities). In principle, two one-mode networks can be projected from GaWC's two-mode datasets (Neal 2008), that is, a city-by-city adjacency matrix (such as the IWCNM as it is commonly studied) and a firm-by-firm adjacency matrix (a dataset detailing the co-location of firms in cities). As a corollary, the IWCNM essentially tells only 'half' of the story, that of the cities. Although this may seem warranted or even logical given that the research focuses on city network formation, network analysts have lamented such a one-sided approach to two-mode networks by pointing to the information loss this engenders (e.g. Breiger 1974; Latapy et al. 2008).

A two-mode perspective on WCN-formation not only recognises that (1) inter-city networks emerge from the daily exchanges amongst branches of a globalised APS firm in different cities, but also that (2) inter-firm networks emerge from, say, information sharing, cooperation, and innovation diffusion among different APS firms in a given city (e.g. Bathelt et al. 2004). Despite its appeal and merit, then, the IWCNM does not do full justice to this 'duality of cities and firms' (cf. Neal 2008) in the formation of WCNs, as the information on how APS firms organise themselves in cities is cast-off: information on which firms co-locate in what cities may be crucial to our understanding of WCN formation, but is being discarded. The purpose of this paper is to complement the research drawing on the IWCNM by presenting a two-mode analysis of the world city/APS firm-nexus as measured in the GaWC data. Neal (2008) has presented such an analysis based on GaWC data for the year 2000.

Here we extend his work by adding a longitudinal element to the analysis, exploring changes in both modes of WCN-formation as measured for 2000 and 2010.

The remainder of this paper is organised as follows. In the next section, we spell out in more detail the differences between a one-mode and a two-mode analysis of the WCN. We then describe our datasets containing information on the presence of 50 globalised APS firms in 154 world cities for the years 2000 and 2010. The ensuing section presents our measurement framework, which entails a description of different centrality measures to analyse the position of nodes in networks. This is followed by a discussion of our results, after which our paper is concluded with a summary of our main findings and suggestions for further research.

THE IWCNM: A TWO-MODE NETWORK

As noted, Taylor's (2001) specification of the WCN essentially starts off as a so-called 'two-mode network', which is characterised by connections between two separate sets of nodes (cities and firms). By contrast, in more conventional one-mode networks, actors are directly interlinked (e.g. cities connected by airline flows). The gist of two-mode networks is that there is no direct linkage within the same set of nodes (i.e. between cities or between firms): researchers simply know which firms are in what cities, and which cities house what firms. Such city-by-firm datasets have been collected as intermediate products in WCN studies that approximate urban networks through an analysis of the organisational structures of multinational enterprises (e.g., Alderson & Beckfield 2006; Hoyler et al. 2008; Wall 2009; Jacobs et al. 2011).

To facilitate our discussion of the implications for the analysis of such data, in what follows we will make use of a sample city-by-firm matrix (Figure 1), excerpted from the GaWC 2000 dataset. This valued matrix describes a two-mode network consisting of five firms (Ernst and Young, HSBC, Jones Day, Boston Consulting, BBDO Worldwide) across five cities (New York, London, Paris, Tokyo and Beijing). The values in the matrix feature the 'linkage' between

cities and firms: The matrix values range from 0 to 5, where 0 indicates absence of a firm, 5 indicates the presence of the firm's headquarters, and the values in-between are a measure of the relative importance of an office in a firm's network. For example, BBDO Worldwide is headquartered in New York, and has a major office (representing a value of 4) in London and a middle-of-the-road office (representing a value of 2) in Beijing.

[FIGURE 1 ABOUT HERE]

To date, most empirical analyses of two-mode networks in general and intercity corporate networks in particular have followed one of two major directions: (1) a direct two-mode examination of the data; or (2) its conversion into a one-mode network.

The direct two-mode network approach allows for a direct examination of the duality, using all the information contained within the city-by-firm data matrix, namely, cities and firms are studied simultaneously. In its simplest form, the two-mode approach treats the city-by-firm network as a multivariate dataset and applies different multivariate statistical methods to reveal patterns in the data (e.g. Taylor 2004; Taylor & Derudder 2004; Taylor et al. 2013a). However, such a straightforward multivariate analysis implicitly falls short of accounting for the interdependence among individual firms' locational strategies, that is, the assumptions of many statistical models require data points to be independent. More advanced two-mode network analyses address this interdependence issue and move on to understanding the underlying dynamics of intercity corporate networks (Liu et al. 2013a).

However, the interpretation of results of two-mode network analysis is not very intuitive, and may therefore be less attractive for urban scholars. For example, the definitions of betweenness and closeness centralities of two-mode networks (Borgatti & Everett 1997) involve both embodied (e.g. firms' presence in cities) and intangible flows (e.g. technological spillovers between firms), making it difficult to interpret the importance of individual cities and firms in a single framework.

A more straightforward and common way to analyse the two-mode city-by-firm network is to derive city-to-city and firm-to-firm one-mode networks through network projections.

While the direct two-mode approach analyses cities and firms simultaneously, the one-mode projection allows us to deal with both modes separately. On the one hand, connections in the projected city-to-city network are forged by the location of offices of an APS firm in different cities, and represent potential intercity connections (Taylor 2001). On the other hand, two firms are deemed as connected in the firm-to-firm network if they co-locate in the same cities, and the extent of co-location suggests the potential for inter-firm information exchange (Neal 2008). Bathelt et al. (2004) claim that the knowledge learning and generation in contemporary knowledge economy are achieved through local interactions ('buzz') as well as knowledge channelled from translocal communications ('pipelines'). Therefore, a firm may benefit from co-locating with others (joining local 'buzz') and expanding office networks (making extensive 'pipelines'), which often lead to co-locations between firms in multiple cities. Moreover, firms' locational strategies are often interrelated (e.g. mimicking and following one another; Liu et al. 2013a).

Both types of one-mode networks are indeed examined in the economic geography and regional studies literature. For instance, research on urban systems focuses on cities as interlocked by infrastructure and multi-locational firms (e.g. Mitchelson & Wheeler 1994), while research on regional clustering focuses on inter-firm networks formed by co-location of firms in cities or regions (e.g. Polenske 2004; Huber 2011).

[FIGURE 2 ABOUT HERE]

[FIGURE 3 ABOUT HERE]

The major drawback of using one-mode projections is that it often inflates the number of linkages in the network: it tends to generate a very dense city connectivity matrix that is hard to handle with network analysis techniques (Latapy et al. 2008). For example, the one-mode intercity and interfirm networks projected from the pedagogic example above represent two fully connected networks (Figure 2b and 3b). Conventional approaches adopted to alleviate this issue include applying thresholds and alternative network projections (Neal 2013, Neal 2014; Hennemann & Derudder, 2013).

Formally, the projection from the two-mode city-by-firm network into the city-to-city and firm-to-firm networks can be defined as (Neal 2008)²:

$$E(c) = V * V^t \quad (1)$$

$$E(f) = V^t * V \quad (2)$$

Where V and V^t represent the original city-by-firm data matrix and its transpose; $E(c)$ is a one-mode network capturing the intensity of potential intercity connections; $E(f)$ is another one-mode network measuring the intensity of potential interfirm connections.

A key point is that Taylor's (2001) interlocking WCN model is essentially a projection from the original intercity corporate network, namely, equation (1). In the context of our empirical focus, the assumption behind (1) and (2) is that the more important an office of firm j in city i , the more links there will be with offices in other cities of firm j 's network as well as with offices of other firms in city i (i.e. a simple interaction model). For the intercity network, the limiting case is a city that shares no firms with any other city so that all of its service value products in equation (1) are 0. Similarly, if a firm does not co-locate with another firm, it will have no connections in the interfirm network produced by equation (2). Such projection implies a 'brute force' process (Neal 2013) where intercity linkages are a function of cities' sizes as represented by the number of firms in individual cities. Similarly, interfirm connections are in part determined by firms' absolute sizes as measured by the number of cities in which individual firms locate.

DATA

To engage in a comprehensive analysis of how positions of firms and cities in the WCN have changed between 2000 and 2010, we make use of the GaWC datasets for 2000 and 2010 to

² Similar to gravity/spatial interaction models, the current projection functions assume that links in the projected city/firm networks are a multiplicative function of city/firm importance. Link weights can also be produced by additive, strongest-link, or weakest-link functions.

explore the evolution of both intercity and interfirm networks. The two-mode GaWC data details the office networks of large professional, financial and creative service firms in cities throughout the settled world. These data collections are described in detail in Taylor et al. (2002) for the year 2000 and in Taylor et al. (2013a) for the year 2010, and will be summarised here as they provide the input to our subsequent analysis. The data collection involved three major steps:

Selection of cities and firms

In 2000, global APS firms were defined as firms with offices in 15 or more different cities, including at least one in northern America, western Europe and Pacific Asia. Firms meeting this criterion were selected from rankings of leading firms in different service sectors. 100 firms were identified in six sectors: 18 in accountancy, 15 in advertising, 23 in banking/finance, 11 in insurance, 16 in law, and 17 in management consultancy. Selecting cities was based upon previous GaWC experience in researching global office networks and also included all capital cities. A total of 315 cities were selected. The end result is a 315 cities by 100 firms matrix.

In 2010, a much larger data collection was performed. A more robust firm selection method was imposed by including all top firms in individual sectors for which data were available. The separate banking/finance and insurance sectors in the 2000 dataset were combined, and the top 75 such firms were selected as ranked in the Forbes composite index, a measure that combines rankings for sales, profits, assets and market value. For each of the other four of the previously studied services – accountancy, advertising, law and management consultancy – the top 25 firms were included based on sectoral rankings (Derudder et al. 2010). Overall, the number of firms was increased from 100 to 175. In addition, the number of cities was increased to 526, adding among others many fast-growing and economically important cities from emerging economies (e.g. China and India). The end result is a 526 cities by 175 firms matrix.

Determination of service values

The next step determines values in the city-by-firm matrix. The GaWC approach to assign 'service values' focuses on two features of a firm's office(s) in a city as shown on their corporate websites: first, office size (e.g. number of practitioners), and second, extra-locational office functions (e.g. regional headquarters). Information for every firm is simplified into service values ranging from 0 to 5. The city housing a firm's headquarters scores 5, a city with no office of that firm scores 0. An 'ordinary' or 'typical' office of the firm scores 2. With something missing (e.g. no partners in a law office), the score is reduced to 1. Particularly large offices score 3 and those with important extra-territorial functions (e.g. regional headquarters) score 4. All such assessments are made firm by firm.

Ensuring data consistency

As the sets of cities and firms collected in 2000 and 2010 are not entirely identical, the challenge is to measure actual structural changes in the WCN rather than changes in the data gatherings. Here we take the easiest route by restricting our analysis to (1) the 50 firms that have 'strong' linkages (see below) in the projected inter-firm network in 2000 and 2010; and (2) the 154 cities that have 'strong' linkages (see below) in the projected intercity network in 2000 and 2010³. As a consequence, the final dataset consists of two 154 cities-by-154 cities intercity and two 50 firm-by-50 firm inter-firm networks. Although this restriction causes a loss of data, it provides necessary consistency for a longitudinal analysis.

And finally, we will also look at changes in the connectivity of cities and firms at a higher level of abstraction, that is, regions (for cities) and sectors (for firms), which may reduce overall network complexity and highlight major patterns. In order to discern regional tendencies in the evolution of intercity corporate networks, we adopt the regionalisation scheme in Taylor et al. (2013a), and assign individual cities into one of the nine major world regions: Europe (49 cities), North America (26), Latin America (22), Pacific Asia (15), Middle

³ Ensuring cities and firms are 'connected' in both years would avoid problems of calculating centrality scores for isolated nodes and generate more comparable centrality scores. This limits our analysis to cities that are already 'connected' in 2000, focusing less on cities that are isolated in 2000 but merged into the network in 2010.

East & North Africa (14), South Asia (9), Sub-Saharan Africa (8), Australia (7), and Eurasia (4). Similarly, firms are labelled with their sectoral affiliations, namely, accountancy (14 firms), consultancy (11), advertising (10), banking and finance (8), and law (7).

METHODS

For both years, we derive an intercity network and an interfirm network using equations (1) and (2). We employ the constant thresholding dichotomisation to circumvent the issue of fully-connected projected networks. An empirical decision is made to consider individual linkages to be strong enough and set to 1 if they are at least 10 per cent of the strongest linkage in corresponding networks and 0 otherwise (a sensitivity analysis is provided in the appendix to justify the use of this 10 per cent threshold; see Butts 2009 for a theoretical discussion of sensitivity analysis). Although it is clear that this dichotomisation creates issues such as loss of information (Opsahl & Panzarasa 2009), dichotomised networks allow for a wide range of network analysis techniques (not limited to the centralities employed in the current context) as well as backward comparisons with previous studies that use binary networks (Neal 2008). This leaves us with a 154-by-154 intercity network and a 50-by-50 interfirm network for 2000 and 2010. Our projection and thresholding methods reflect a theoretical ‘brute force’ perspective on intercity/interfirm interactions (i.e. stronger connections are more important, as they connect cities of sheer economic size), which has been employed in most previous analyses. We adopt this conventional projection method to ensure a consistent comparison with previous findings. Nevertheless, we note that alternative theoretically-driven projections, such as a ‘sorting process’ method during which firms are sorted into cities (Neal 2013), are suitable for revealing other aspects of world city formation. In addition, we do not employ other projection methods (Alderson & Beckfield 2004; Hennemann & Derudder 2013) that (1) are suitable to derive intercity relations but not interfirm connectivity; (2) produce sparse intercity networks in the case of a rather limited number of firms; and/or (3) restrain the number and types of offices to be included in the analysis.

We assess the network positions of individual cities and firms with three network centrality measures: degree, closeness, and betweenness centrality. Following Alderson et al. (2010), we illustrate the implications of these centrality measurements with pedagogic networks. The two networks (Figure 4) represent connections between cities and firms if we treat the nodes as cities and firms, respectively. The star network (Figure 4a) exhibits a hierarchical scenario, in which a firm or city with the position of A clearly holds a more central position than other nodes in the network. In contrast, the circle network (Figure 4b) represents a flat network, with all nodes attaining the same structural positions.

[FIGURE 4 ABOUT HERE]

Degree centrality measures individual nodes' direct linkages to other nodes in the network. For example, node A in the star network has an advantageous position as it has more access to other nodes in the network. For the intercity network, this means that the city in position A has more peers to connect with than the other three cities (B, C, D), that is, city A has a larger pool of potential connections. Similarly, firms with more connections tend to have greater possibilities for interaction, such as co-operation and information sharing. By contrast, all nodes in the circle network have exactly the same number of linkages and are therefore equally positioned in the network.

Closeness centrality measures individual nodes' inverse distances to all other nodes. For the intercity network, cities with larger closeness have more direct and indirect access to other cities, whereas a larger closeness in the interfirm network reflects less intermediate steps/time that a firm needs to access information/innovations generated by other firms. In this regard, node A in the star network is advantaged and has a larger closeness score: its sum of inverse distance to other nodes ($1/1 + 1/1 + 1/1 = 3$) is greater than that of nodes B-D ($1/2 + 1/2 + 1/1 = 2$). By contrast, all four nodes (A-D) in the circle network have equal closeness scores ($1/1+1/1+1/2 = 2.5$).

Betweenness centrality captures nodes' tendency for performing brokerage roles, i.e. controlling or facilitating interactions between other nodes. In the star-like intercity network, business connections between cities B-D (or B-C or C-D) cannot bypass city A,

whereas city A requires no intermediate cities to conduct business with other cities. Hence A has a betweenness of 3 for the entire network, whereas the betweenness centrality of B, C, and D equals 0. Similarly, firms in positions A can control the exchange of information and innovation between other pairs of firms, achieving a certain degree of monopoly on information spillovers. In comparison, nodes A-D in the circle network are equally advantaged/disadvantaged in controlling flows between other pairs of nodes: all nodes have a betweenness centrality of 1.

RESULTS

Thus far, we have described (1) the two-mode network underlying Taylor's IWCNM and the potential offered by exploring both modes of the intercity corporate network, (2) the transformation of the data to arrive at consistent sets of intercity and interfirm networks for 2000 and 2010, and (3) the key tenets of three commonly used centrality measures in network analysis. Combined, this gives us the opportunity to assess the following questions, which will be used to organise the discussion of our results:

- How have intercity and interfirm networks changed over time?
- Have intercity and interfirm networks become more or less hierarchical?
- What are the regional and sectoral tendencies in the evolution of intercity and interfirm networks?

How have intercity and interfirm networks changed?

Before entering the discussion of changes in the intercity corporate network between 2000-2010, it is helpful to take a small detour and examine the robustness of our analysis by assessing whether city and firm rankings are consistent with previous studies (Table 1 and 2)⁴. On the one hand, cities' ranks for 2000 and 2010 are largely in line with those identified based on the fuller GaWC datasets (Taylor et al. 2002, 2014; Derudder et al. 2010) and/or

⁴ For ease of interpretation, all centrality scores are normalised. An overview of normalisation of centrality scores in one- and two-mode networks can be found in Borgatti & Everett (1997).

different intercity networks (Smith & Timberlake 2001; Alderson & Beckfield 2010). For example, our analysis confirms that major cities in the emerging economies (e.g. Dubai and Mumbai) rise into the top of the global urban hierarchy, whereas a number of established first tier cities (e.g., New York, London, Hong Kong, and Paris) maintain their leading positions (Table 1). On the other hand, the rankings of firms reported here are also consistent with previous findings (Neal 2008), with banks and accounting firms assuming leading positions in the interfirm network (Table 2). Therefore, despite using a subset of the GaWC dataset, our analysis of both modes in the intercity corporate network appears to generate intercity and interfirm networks that largely coincide with previous studies.

[TABLE 1 ABOUT HERE]

[TABLE 2 ABOUT HERE]

While there seems to be little variation among the top cities in the three centrality rankings for individual years, the inequalities within individual rankings vary, suggesting ‘a hierarchy of hierarchies’ (Neal 2008). Note that the use of ‘hierarchy’ in the context of global urban/firm networks is different from that in network science: the former focuses on the uneven distribution of centralities among nodes, while the latter is more related to directions of network linkages. The Gini coefficients⁵ of closeness centrality are smallest (Table 4), reflecting that cities/firms can reach other with a few intermediate steps. Degree centralities for both cities and firms are more hierarchical, as there are nonetheless sizable differences in the level of integration in the networks. The unevenness within betweenness centrality is the most extreme, because there are only a few cities and firms that are privileged with brokerage roles in the intercity and interfirm networks (Neal 2008).

Our results suggest that the global firm network has undergone extensive change, as the correlations between centrality scores in 2000 and 2010 are moderate at best (Table 3; see also QAP correlations in the appendix). In comparison, the global urban hierarchy is more

⁵ Larger Gini coefficients represent greater inequality among centrality scores. A Gini coefficient of 0 indicates total equality, whereas a value of 1 suggests extreme inequality. Gini coefficient is often used to measure income inequality, and we adopt it here to measure the unequal distribution of centralities among cities/firms.

stable in terms of correlation between centrality scores in different years. With limited supplementary data, the task of identifying the determinants of observed changes goes beyond the scope of the current paper. However, a few conjectures can be made: these changes may reflect recent upheavals in the global geo-economic structure, or they may reflect long-term organisational changes of producer services firms (e.g. mergers, acquisitions, joint ventures, and other forms of strategic alliances).

[TABLE 3 ABOUT HERE]

The most notable feature in this transition is the overall integration in intercity and interfirm networks during the period 2000-2010, as evidenced by a number of related indicators: the average degree centralities for cities and firms increase substantially between 2000 and 2010. With the 10 per cent threshold, the interfirm network is close to fully connected in 2010 (Table 3). Individual cities are able to establish more direct economic connections with other cities, whereas firms are able to benefit from interacting directly with a larger number of firms. This enhanced integration shrinks distances among cities and firms, so that closeness centrality increases for both cities and firms. Furthermore, average betweenness centralities decline for interfirm networks, as fewer firms occupy brokerage positions when interfirm networks become more connected (Table 7). Similar observations can be made for intercity networks: As former 'peripheral' regions are rapidly integrating into the global urban network (at least those produced by APS firms), North American and European cities' betweenness centralities relatively decline.

As noted earlier, the urban hierarchy is more stable and steeper than the firm hierarchy. The correlations between centrality scores of cities during 2000-2010 are generally greater than those of firms, that is, the shuffling of ranks is more volatile in the interfirm network (Table 3). For example, 22 firms entered the top fifteen positions in centrality rankings during 2000-2010. The most noticeable example of stability is the consistent dominance of New York and London (NY-LON) in the intercity network (Neal 2008; Taylor et al. 2013a). Despite the emergence of an increasingly connected intercity network, NY-LON consistently ranks atop all centrality rankings (Table 1). NY-LON's dominance is especially evident in the ranking of betweenness centrality: New York and London are the only true brokerage nodes,

coordinating a sizeable amount (around 10 per cent for 2010) of all intercity connections in both years. By contrast, no firm exhibits a similar dominance in the interfirm network.

[TABLE 4 ABOUT HERE]

Have intercity and interfirm networks become more or less hierarchical?

There are, in principle, different conjectures about the global distribution of connectivity in the new urban hierarchy. At one end of the spectrum, the intercity network can be expected to become more hierarchical with command-and-control functions of the global economy increasingly concentrating in a limited set of cities (Friedmann 1986; Sassen 2001). At the other end, a lessening of hierarchical tendencies in the global urban arena has been suggested, with cities in the Global South quickly integrating into the world city network as office networks have extended into other regions (Derudder et al. 2010). Therefore, we assess the temporal changes of inequality among cities' connectivity by tracing Gini coefficients of centrality rankings in different years.

The results in Table 4 point to mixed tendencies. On the one hand, the distributions of degree and closeness centrality become more even during 2000-2010, suggesting that cities become similar in terms of number of strong economic linkages as well as average distances to others. On the other hand, the unevenness among betweenness centralities remains rather constant, despite more cities integrating into the world city network and making average betweenness centrality scores decline.

There are also different hypotheses about hierarchical and heterarchical processes in the interfirm network. On the one hand, firms with more branches in 2000 tend to continue their expansive strategies, achieving a higher level of integration into the interfirm network and thus potentially amassing additional structural advantage (Liu et al. 2013a). For example, acquisition and mergers among firms usually concentrate market power into fewer players (Neal 2008). On the other hand, while globalised spatial strategies were just for the 'happy few' at the dawn of this century (Wall et al. 2011), more firms are now equipped/motivated to pursue a worldwide presence, narrowing the gaps between firms'

connectivity and creating a flatter firm hierarchy. Further complications are brought about by the recent global economic crisis, during which many financial services as well as other advanced producer services have undergone substantial reorganisation.

Our analysis (Table 4) suggests that while the interfirm network is becoming more integrated and even, the brokerage/control functions, as captured by betweenness centrality, remain modestly unequal among firms. The decreasing inequality among degree and closeness centralities is consistent with the overall rise of network connectivity. Meanwhile, the decreasing but still sizeable Gini coefficients for betweenness centralities suggest that the power to control information sharing and diffusion remains modestly concentrated in the integrated interfirm network.

While both networks exhibit a mix of hierarchical and heterarchical processes, the inequality in the intercity network tends to be greater than that in interfirm networks. This confirms previous observations that a small set of strategic places retain crucial positions in the provision of advanced producer service in contemporary globalisation (Neal 2008; Taylor et al. 2014).

What are the regional and sectoral tendencies in the evolution of intercity and interfirm networks, respectively?

Regional and sectoral tendencies in the evolution of intercity and interfirm networks are assessed based on the average centralities of individual regions and sectors (Table 5). Where regionality has been a persistent feature of intercity networks (Taylor et al. 2001, 2013a), centralities of different regions in intercity networks have also been found to be converging (Alderson et al. 2010; Mahutga et al. 2010): the regional inequalities among average centralities are becoming less steep, i.e. erstwhile 'peripheral' regions are catching up in terms of their integration in APS networks. Cities in Middle East & North Africa (MENA), South Asia, and Eurasia, for instance, are characterised by above-average growth in centrality scores (Table 6). The claim about the rise of MENA is particularly robust, as more cities from this region have been included in our sample than other regions experiencing growth (e.g. South Asia and Sub-Saharan Africa). In addition, leading cities in MENA, such as

Dubai, have risen considerably in city rankings (see Table 1). However, the unevenness for the betweenness centrality is still the most pronounced one among the three centrality measures (Table 5) – despite that overall betweenness centralities are decline, the command-and-control functions of advanced producer servicing have largely concentrated in the worlds’ three major urban arenas: North America, Europe, and Pacific Asia.

Law and consultancy firms appear to enjoy above-average growth in closeness and degree centrality and relatively less decline in betweenness centrality (Table 7). Advertising and accounting firms seem to endure slower expansion rates in the selected 154 cities. When these changes of centralities in law and consultancy are jointly examined with the geographic distribution of individual firms (Rossi & Taylor 2006; Taylor et al. 2013a), these diverging growth trends in different sectors may represent distinct globalisation processes, *extensive* and *intensive* (Taylor et al. 2013b). This dichotomisation builds upon a ‘core-periphery’ perception of the world-system, which consists of a densely interconnected ‘core’ and many less-connected ‘peripheries’ (Alderson & Beckfield 2004). Extensive globalisation is characterised by linkages between the core (e.g. NY-LON) and periphery (e.g. the Global South), whereas intensive globalisation focuses more on the intensification of linkages within the core. Accounting firms often contribute to extensive globalisation, as they usually have very large office networks. In fact, the largest firms in our dataset (e.g. KPMG, Pricewaterhouse, and Deloitte), in terms of number of branches, are mainly accounting firms. Advertising and accounting firms under investigation have undergone extensive expansion in the selected 154 cities⁶ at the beginning of our study period, thus appearing to be expanding less aggressively during 2000-2010. On the contrary, the office networks of management consultancy and law firms are often concentrated in the world’s major urban arenas, and are thus more involved in intensive globalisations (Taylor et al. 2014).

⁶ In a relative sense, the selected 154 cities could be deemed as an enlarged ‘core’ of the global economy as these cities are connected (have strong economic relationships) for both years.

CONCLUSIONS

In this paper, we explored the temporal evolution of both cities and firms in a two-mode intercity corporate network formed by 50 leading advanced producer service firms across 154 cities. Drawing upon one-mode network projection and three network centrality measures, we assess how individual cities and firms evolve in intercity and interfirm networks. Our dataset is derived from GaWC datasets collected in 2000 and 2010.

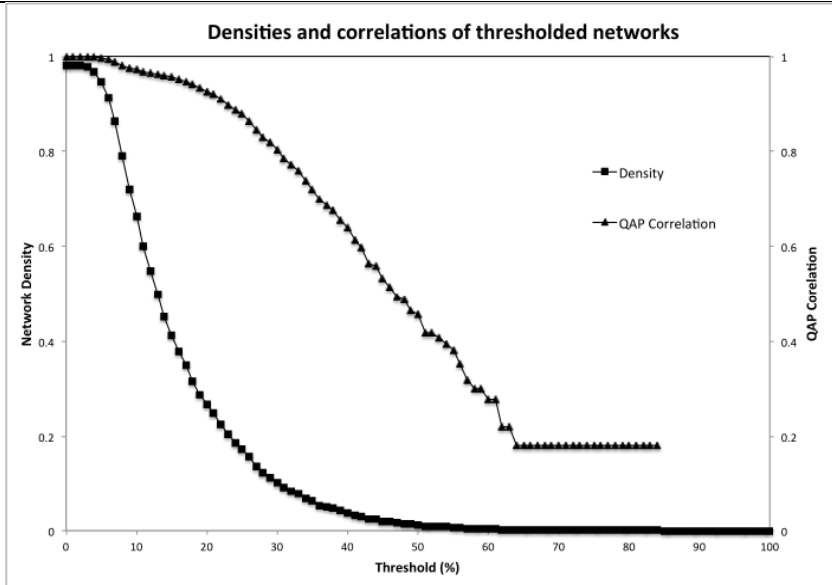
Our analysis suggests that the global urban and firm networks contained in GaWC data have undergone extensive changes between 2000 and 2010. The most notable feature in this transition is the overall rise of connectivity in intercity and interfirm networks. Although both intercity and interfirm networks are shifting, the urban hierarchy is more stable and steeper than the firm hierarchy. Both intercity and interfirm networks are becoming more connected, but the brokerage/controlling functions in the intercity networks have remained rather centralised, reflecting a mixture of hierarchical and heterarchical processes. We also explored cities and firms at aggregated scales, such as regions and sectors. For the intercity network, regional inequalities among average centralities are decreasing. For the interfirm network, sectoral dynamics are different, with law and consultancy firms achieving above-average growth in centralities.

We explored both modes (i.e. cities and firms) in the intercity corporate network separately. Scope for future extension of this line of research lies in (1) comparing one-mode networks constructed by different projection methods (Neal 2014); (2) exploring centralities of cities and firms simultaneously, with future advancement in direct two-mode network analysis (Borgatti & Everett 1997); (3) employing advanced network visualisations (Vinciguerra et al., 2010; Liu et al. 2013b); and (4) network normalisation should be employed in future analysis, as direct comparisons of network metrics calculated for networks of different sizes (e.g. the comparison between intercity and interfirm networks) may produce spurious results (van Wijk et al. 2010). In addition, given our focus on methodological refinements to Taylor's (2001) IWCNM, our interpretations of the results have been restricted to conjecture: more substantive understandings, fuelled by qualitative research are therefore

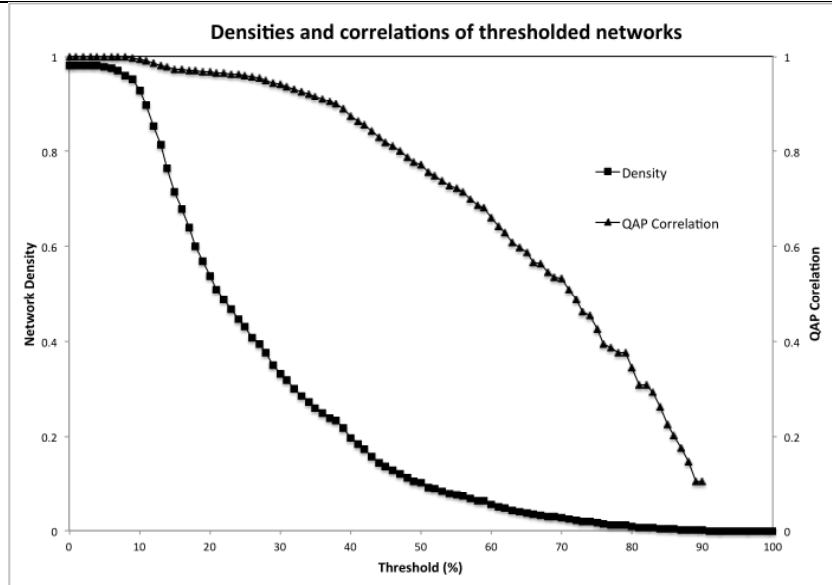
needed to realise the potential of such a refined methodological approach (Parnreiter 2014; Watson & Beaverstock 2014).

Appendix 1. QAP correlation between the original network and the network after applying a threshold (as a proportion of the strongest dyad)

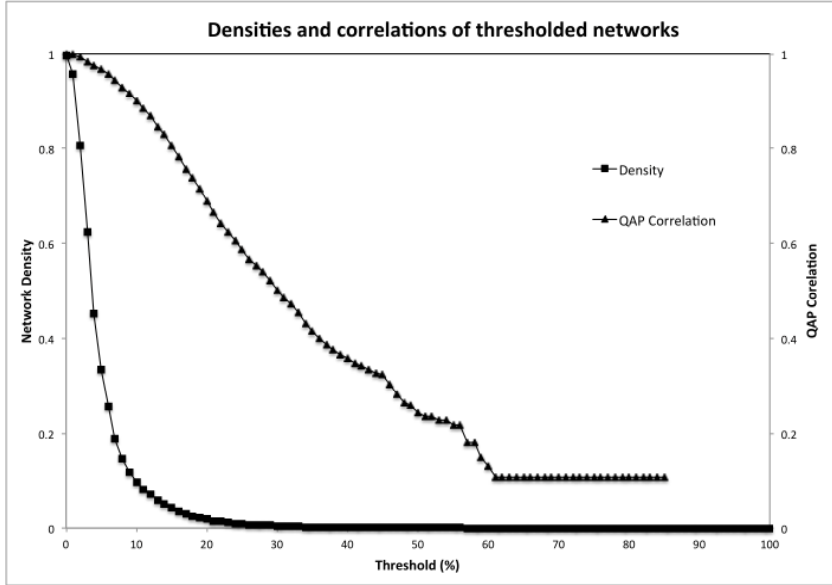
Firm 2000



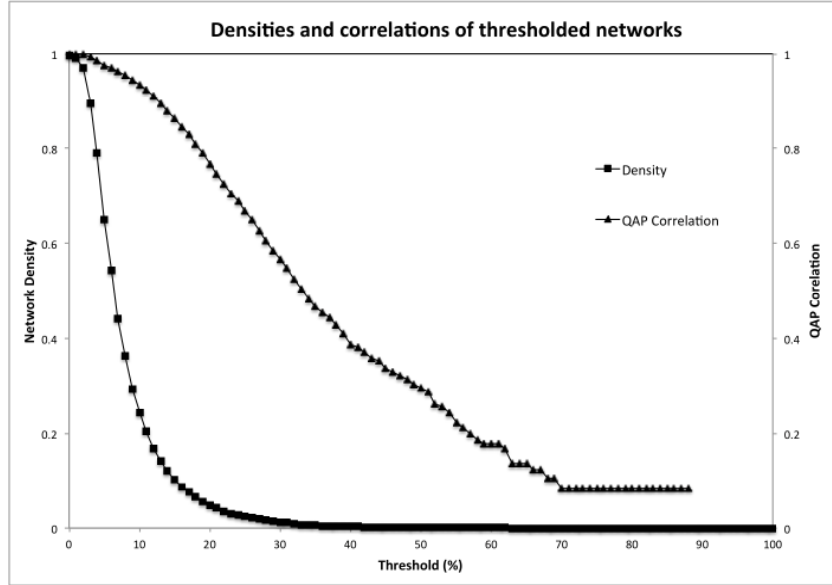
Firm 2010



City 2000



City 2010



To circumvent the problem of fully connected projected networks, we impose a dichotomisation threshold at 10 per cent of the strongest dyad in original networks. The resulting network has a much lower density, but nonetheless a sizable QAP correlation (with correlation coefficients > 0.9 in most cases; QAP, Quadratic Assignment Procedure, see Hanneman & Riddle 2005) with the original network: this implies that the structure of dichotomised network closely mimics the structure of the original network, but with a density that only the meaningful or 'strong' links are retained. Other thresholds such as 5 per cent, 15 per cent and 20 per cent have also been tested, and overall trends in the analysis remain, despite that specific orderings of hierarchies may shift with different thresholds.

The number of linkages in thresholded networks are as follows: 2393 (intercity 2000), 5446 (intercity 2010), 800 (interfirm 2000), and 1090 (interfirm 2010). The QAP correlation between intercity networks in 2000 and 2010 is 0.5386, and the QAP correlation between interfirm networks in 2000 and 2010 is 0.3423. Both correlations are significant at the 0.01 level.

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TABLES AND FIGURES

Table 1. Centrality rankings of cities

	Degree		Closeness		Betweenness	
Rank	City	Score	City	Score	City	Score
2000						
1	New York	1.0000	New York	0.9563	New York	0.3098
2	London	0.9932	London	0.9503	London	0.2973
3	Paris	0.6712	Paris	0.7356	Paris	0.0285
4	Amsterdam	0.6575	Amsterdam	0.7286	Hong Kong	0.0250
5	Hong Kong	0.6507	Hong Kong	0.7251	Toronto	0.0246
6	Toronto	0.6233	Toronto	0.7116	Amsterdam	0.0226
7	Tokyo	0.5959	Tokyo	0.6986	Tokyo	0.0117
8	Milan	0.5822	Milan	0.6923	Milan	0.0101
9	Madrid	0.5685	Madrid	0.6861	Chicago	0.0098
10	Singapore	0.5685	Singapore	0.6861	Madrid	0.0078
11	Los Angeles	0.5548	Los Angeles	0.6800	Los Angeles	0.0072
12	Chicago	0.5479	Chicago	0.6770	Singapore	0.0072
13	Sydney	0.5411	Sydney	0.6740	Brussels	0.0055
14	Brussels	0.5342	Brussels	0.6711	Frankfurt	0.0050
15	Sao Paulo	0.5342	Sao Paulo	0.6711	Sydney	0.0049
2010						
1	London	1.0000	London	1.0000	London	0.1014
2	New York	0.9869	New York	0.9871	New York	0.0753
3	Hong Kong	0.9281	Hong Kong	0.9329	Hong Kong	0.0282
4	Paris	0.9150	Paris	0.9217	Paris	0.0233
5	Singapore	0.9085	Singapore	0.9162	Dubai	0.0211
6	Dubai	0.9085	Dubai	0.9162	Chicago	0.0196
7	Chicago	0.9020	Chicago	0.9107	Singapore	0.0183
8	Sydney	0.9020	Sydney	0.9107	Sydney	0.0178
9	Amsterdam	0.8889	Amsterdam	0.9000	Milan	0.0162
10	Mumbai	0.8889	Mumbai	0.9000	Amsterdam	0.0150
11	Tokyo	0.8824	Tokyo	0.8947	Mumbai	0.0149
12	Milan	0.8824	Milan	0.8947	Tokyo	0.0129
13	Kuala Lumpur	0.8627	Kuala Lumpur	0.8793	Kuala Lumpur	0.0115
14	Toronto	0.8562	Toronto	0.8743	Toronto	0.0099
15	Sao Paulo	0.8562	Sao Paulo	0.8743	Sao Paulo	0.0099

Table 2. Centrality rankings of firms

	Degree		Closeness		Betweenness	
Rank	Firms	Score	Firms	Score	Firms	Score
2000						
1	KPMG	1.0000	KPMG	0.9608	KPMG	0.0561
2	PwC	0.9787	PwC	0.9423	PwC	0.0558
3	Deutsche Bank	0.9362	Deutsche Bank	0.9074	Mitsubishi UFJ	0.0442
4	Mizuho	0.9362	Mizuho	0.9074	Deutsche Bank	0.0246
5	McCann Erickson	0.9362	McCann Erickson	0.9074	Mizuho	0.0246
6	RSM	0.9362	RSM	0.9074	McKinsey	0.0245
7	Barclays	0.9149	Barclays	0.8909	McCann Erickson	0.0218
8	AGN	0.9149	AGN	0.8909	RSM	0.0218
9	Crowe Horwath	0.9149	Crowe Horwath	0.8909	Barclays	0.0149
10	HLB	0.9149	HLB	0.8909	HSBC	0.0132
11	JWT	0.9149	JWT	0.8909	AGN	0.0099
12	McKinsey	0.8936	McKinsey	0.8750	Crowe Horwath	0.0099
13	BBDO	0.8936	BBDO	0.8750	HLB	0.0099
14	PKF	0.8936	PKF	0.8750	JWT	0.0099
15	BNP Paribas	0.8936	BNP Paribas	0.8750	BBDO	0.0082
2010						
1	KPMG	1.0000	KPMG	1.0000	KPMG	0.0065
2	McCann Erickson	1.0000	McCann Erickson	1.0000	McCann Erickson	0.0065
3	HSBC	1.0000	HSBC	1.0000	HSBC	0.0065
4	BDO	1.0000	BDO	1.0000	BDO	0.0065
5	Deloitte	1.0000	Deloitte	1.0000	Deloitte	0.0065
6	IBM	1.0000	IBM	1.0000	IBM	0.0065
7	Baker Tilly	1.0000	Baker Tilly	1.0000	Baker Tilly	0.0065
8	PwC	0.9796	PwC	0.9800	Mitsubishi UFJ	0.0056
9	Mitsubishi UFJ	0.9796	Mitsubishi UFJ	0.9800	Mizuho	0.0056
10	Deutsche Bank	0.9796	Deutsche Bank	0.9800	PwC	0.0026
11	RSM	0.9796	RSM	0.9800	Deutsche Bank	0.0026
12	AGN	0.9796	AGN	0.9800	RSM	0.0026
13	HLB	0.9796	HLB	0.9800	AGN	0.0026
14	PKF	0.9796	PKF	0.9800	HLB	0.0026
15	Moore Stephens	0.9796	Moore Stephens	0.9800	PKF	0.0026

Note: PwC = PricewaterhouseCoopers

Table 3. Change of average centrality scores

Cities	2000	2010	COR(2000/2010)
Degree	0.2129	0.4623	0.8601
Closeness	0.5600	0.6737	0.8455
Between	0.0053	0.0035	0.9133
Firm	2000	2010	COR(2000/2010)
Degree	0.6528	0.8898	0.5907
Closeness	0.7509	0.9141	0.5712
Between	0.0080	0.0023	0.4008

Table 4. Temporal evolution of hierarchies among cities and firms

Cities	Degree	Close	Between
2000	56.09	11.17	95.97
2010	35.3	10.87	85.44
Firms	Degree	Close	Between
2000	23.64	10.28	73.2
2010	7.79	5.45	49.31

Table 5. Temporal evolution of hierarchies among regions and sectors

Regions	Degree	Close	Between
2000	23.85	4.72	70.99
2010	13.98	4.18	37.67
Sectors	Degree	Close	Between
2000	12.63	5.43	43.66
2010	5.64	3.95	30.58

Table 6. Growth rates (%) for regions

Growth rate 2000-2010	Degree	Close	Between ⁷
AUSTRALIA	99.18	17.72	224.71
EURASIA	248.10	30.20	1270.42
EUROPE	106.94	21.26	-46.28
LATIN AMERICA	96.52	12.68	195.27
MENA	234.57	20.73	2841.67
NORTH AMERICA	105.73	21.14	-61.57
PACIFIC ASIA	88.89	26.81	100.95
SOUTH ASIA	215.59	22.39	1343.40
SUB-SAHARAN AFRICA	214.80	12.67	65.36
WORLD	117.17	20.29	-32.92

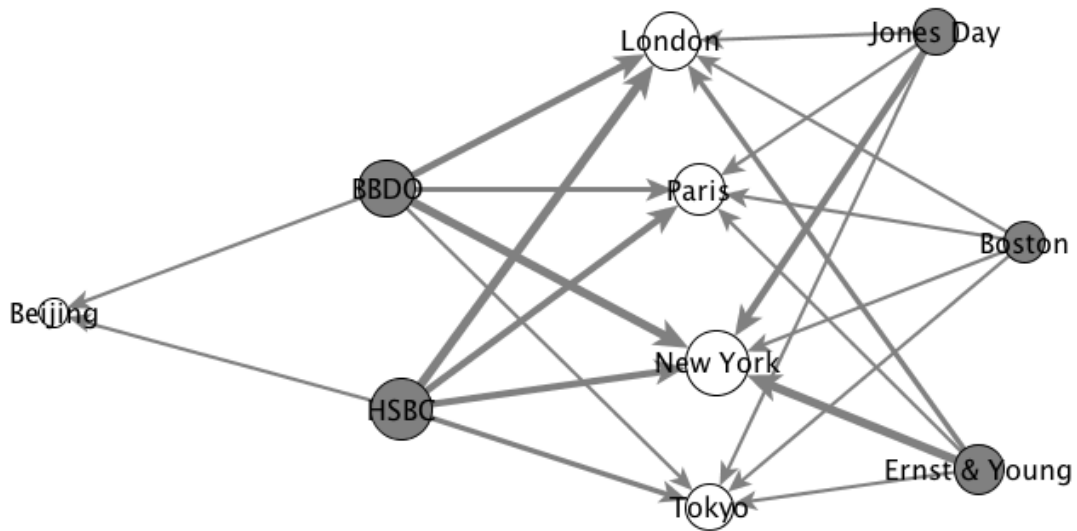
⁷ Note: Regions with growth rate labelled as NA have zero betweenness centrality in 2000.

Table 7 Growth rates (%) for sectors

Growth rate 2000-2010	Degree	Close	Between
ACCOUNTING	24.49	19.65	-72.70
ADVERTISING	25.26	15.18	-70.88
BANKING	18.72	14.37	-81.97
CONSULTANCY	96.52	29.97	-59.86
LAW	59.65	32.58	-20.80
ALL SECTORS	36.31	21.73	-71.28

Figure 1. (a) Pedagogical city-by-firm matrix.

City/Firm	Ernst & Young	BBDO	HSBC	Jones Day	Boston
Beijing	0	2	2	0	0
London	3	4	5	2	2
New York	5	5	4	4	2
Paris	2	3	4	2	2
Tokyo	2	2	3	2	2

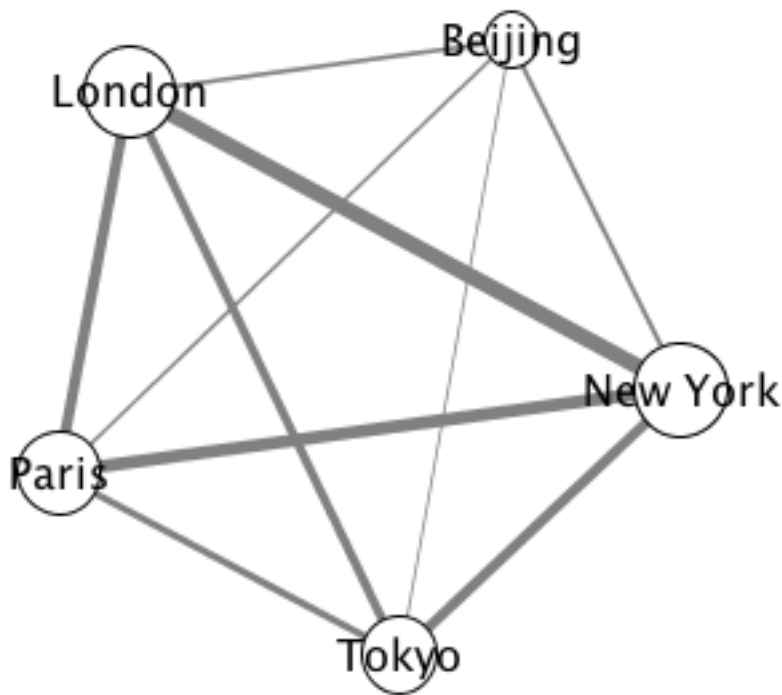


White and grey circles represent cities and firms, respectively. Link width is proportional to the number (total value) of linkages, and the nodal size is proportional to cities' total out degree and in degree.

Figure 2. Inferred interlocking city network (diagonal elements are set to zero) and its graphical representation.

	Beijing	London	New York	Paris	Tokyo	GCC
Beijing	0	18	18	14	10	60
London	18	0	67	46	37	168
New York	18	67	0	53	44	182
Paris	14	46	53	0	30	143
Tokyo	10	37	44	30	0	121
GCC	60	168	182	143	121	

GCC = Global City Connectivity (Equivalent to Global Network Connectivity (GNC) in Taylor 2001), the total number of linkages of individual cities.

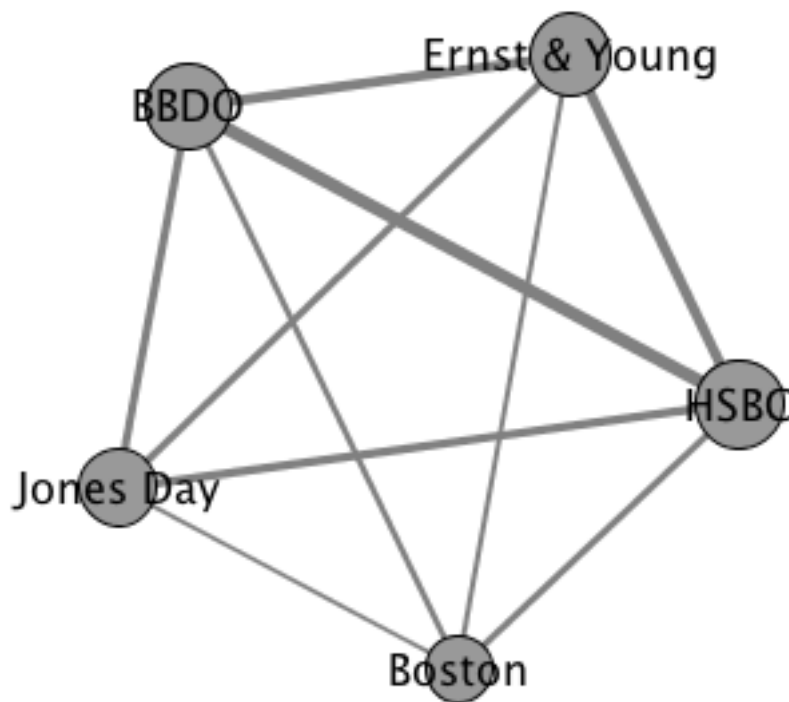


Link width is proportional to the number of linkages, and the nodal size is proportional to cities' GCC.

Figure 3. Inferred interlocking firm network (diagonal elements are set to zero) and its graphical representation.

	Ernst & Young	BBDO	HSBC	Jones Day	Boston	GFC
Ernst & Young	0	47	49	34	24	154
BBDO	47	0	62	38	28	175
HSBC	49	62	0	40	32	183
Jones Day	34	38	40	0	20	132
Boston	24	28	32	20	0	104
GFC	154	175	183	132	104	

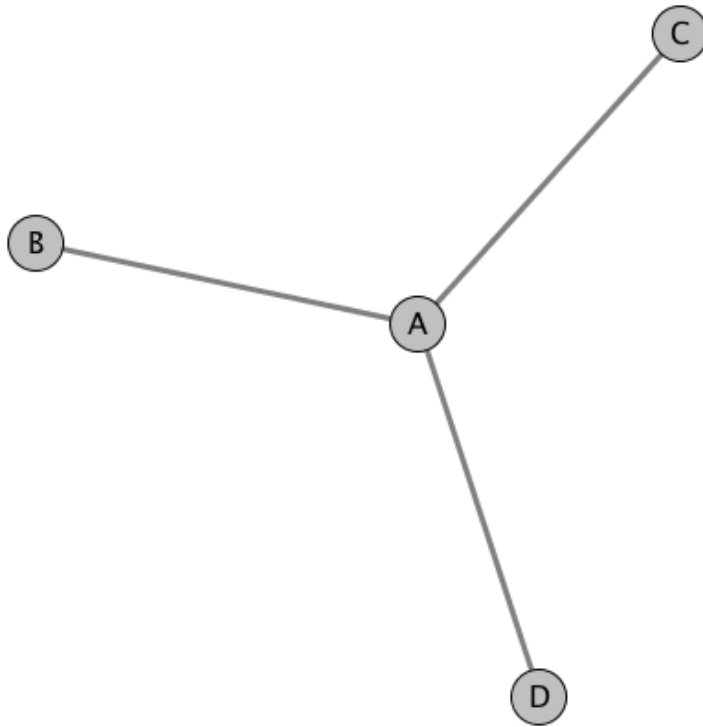
GFC = Global Firm Connectivity, the total number of linkages of individual firms.



Link width is proportional to the number of linkages, and the nodal size is proportional to firms' GFC.

Figure 4. Star-like and circle networks

a. Star-like network



b. Circle network

