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Zachary Neal

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Abstract

Centrality and power have become common foci for world city network research and frequently serve as tools for describing cities' position or status in the system. However, these concepts are difficult to define and measure. Often they are treated as equivalent: more central cities have more power. This paper challenges this assumed equivalence by proposing conceptually distinct definitions and developing two new measures that allow them to be differentiated empirically. Applying the proposed measures in a hypothetical world city network and the Internet backbone network reveals that centrality and power are distinct and suggests that world cities should be viewed as arising from multidimensional network positions that define multiple types: quintessential world cities that are both central and powerful (such as New York and London), hub world cities that are central but not powerful (such as Washington and Brussels) and gateway world cities that are powerful but not central (such as Miami and Stockholm).

Recent research on world urban systems has been characterised by a shift away from viewing cities as hierarchically organised and towards conceptualising the system as a network of intercity relations: a world city network. As a result, such intrinsically relational constructs as centrality and power have become common foci of interest and frequently serve as tools for describing cities' position or status in the system (see for example, Smith and Timberlake, 2001; Alderson and Beckfield, 2004; Choi *et al.*, 2006). However, these concepts are difficult to define and measure. The most common approach to measuring a city's centrality in the world city network involves counting its total number of relationships or network connections. Yet, do all relationships contribute equally to a city's centrality, or are some relationships more valuable than others? Similarly, it is often assumed that cities occupying more central positions in the world city network are more powerful and able to control or influence the flow of

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resources (for example, Taylor, Walker *et al.* 2002; Alderson and Beckfield, 2004; Alderson *et al.*, 2010; Ma and Timberlake, 2008). Yet, is power a consequence of centrality, or are these two relational constructs distinct? More than simply an issue of methodology and language, a robust set of concepts and tools for describing cities' relationships is essential for understanding the world city network and world city formation.[1]

To provide a framework for answering such questions, this paper explores the relationship between centrality and power, and develops an approach for their measurement and differentiation. First, viewing centrality in the world city network as a force that concentrates resources or allows them to be efficiently diffused, a recursive conception of centrality is proposed wherein a city's centrality depends on the centrality of the cities to which it is connected. Secondly, viewing power in the world city network as the ability to control resource flows between cities, a similarly recursive conception of power is proposed wherein a city's powerfulness depends on the *lack of* centrality of the cities to which it is connected. These two measures are applied to two different world city networks: the hypothetical network described by Friedmann (1986) that initiated the earliest research in this area; and, the Internet backbone network originally analysed by Choi *et al.* (2006). Results suggest that centrality and power are theoretically and empirically distinct constructs worth differentiating and that the proposed measures identify positional characteristics missed by more traditional measures.

This paper is organised in four sections. The first section briefly reviews how the concepts of centrality and power are currently discussed and measured in world city network research. In the second section, an alternative approach to measuring centrality is developed that draws on theories of social capital, and a related measure of power is developed that draws on theories of social exchange. The third section demonstrates the utility of these new measures by applying them to hypothetical and observed world city networks. The paper concludes with a discussion of the implications of cities' centrality and power, as defined in the proposed ways, on processes of globalisation and world city formation.

Background

At least since Friedmann's (1986) world city hypothesis, the notions of centrality and power have featured prominently in discussions of world cities and the world city network. Indeed, it would be quite surprising to find a paper in this body of literature that did not use both terms at least once. However, they are often used in loose or imprecise ways that challenge their utility as analytical tools.[2] In this section I briefly consider how these concepts have been used as theoretical constructs and how they have been measured in empirical applications.

Centrality, as applied to cities in the context of globalisation and world city networks, has been identified as the catalyst for two related but opposite processes: concentration and diffusion. First, centrality has been used to denote the concentration of resources in particular cities or, more accurately, the structural arrangement of resource flows that facilitate such concentration. Friedmann's world city hypothesis argued that

> key cities throughout the world are used by global capital as basing points [and that] world cities are major cites for the concentration and accumulation of international capital (Friedmann, 1986, p. 73).

These interrelated hypotheses highlight how centrality—that is, being enmeshed in exchanges of resources or in what Castells (1996) called the 'space of flows'—is a driving force behind the emergence of world cities. Sassen (2010) further developed these ideas by noting that, as networks serve to concentrate resources in particular places, new forms of territorial centrality arise, including not only the traditional downtown business centre, but also the suburbs as emerging centres of global finance. Indeed, although some have suggested that networks of transport and communication have reduced the importance of place by creating a 'flat world' (Friedman, 2005), it is far more likely that these networks, through their ability to concentrate resources in highly central cities, have exacerbated the unevenness of the global urban landscape (Florida, 2005). Thus, in many instances, cities' centrality within a world city network is viewed as a new mechanism for capital accumulation where a central location in space is augmented by a central location in networks of resource exchange.

However, centrality has been used to describe the structural arrangement of resource flows that facilitate the diffusion of ideas, capital and people. That is, a central position in the world city network can lead not only to the concentration of resources within a city but, by providing a city with a wider reach, can also lead to the efficient diffusion of those resources throughout the network. Adopting a diffusion view of centrality, Wheeler and Mitchelson (1989) examined the flow of information among US cities as indicated by Federal Express shipments, finding that commonly cited examples of American world cities (New York, Chicago, Los Angeles) were key sites of information creation and dissemination, rather than information concentration. These cities' ability to 'get the word out' was facilitated by their central position within the Federal Express network. Similarly, centrality within air traffic networks allows some cities to deliver business services more effectively to increasingly global hinterlands (Neal, 2010a, 2010b). Often, these two aspects of centrality—concentration and diffusion—intersect to provide cities with a double structural advantage, as sites where capital converges and collects from many sources, but also as sites where innovations and reputation can be spread rapidly and widely throughout the network. In this paper, although I do not distinguish between its roles facilitating the concentration and diffusion of resources, I do adopt a specifically structural conception of the source of cities' centrality: each city's centrality is a function of its position within the world city network.

Together with centrality, power is a dominant concept in the study of world cities, but one that is difficult to address with precision because it has been used in such diverse ways. Noting that cities are key sites for multinational corporate headquarters, some connect cities' power to their roles as centres of command-and-control in the global economy (Sassen, 1991). Others view cities as powerful to the extent that they can dominate other cities, whether via traditional world systems dichotomies (Friedmann, 1986; Derudder *et al.*, 2010), or through the structure of global supply chains (Hesse, 2010). Still others, who adopt an actor–network theory approach, view power as systemic rather than concentrated in individual cities. For example, Allen argues that

> power does not radiate out from any given centre, as much as it runs along the length and breadth of a network (Allen, 2009, p. 203; see also Grewal, 2008).

This proliferation of conceptions of power has led to the development of several typologies of power (Allen, 1997, 2009) and has forced researchers to employ "an eclectic theoretical position" that attempts to merge these into a unified idea (Taylor, 2004, p. 88). Thus, it is important to be clear what version of power I intend to address. In this paper, I focus on what Dahl (1957) initially described as 'power over' and what Allen (1997) later described as 'power as a capacity'. This approach equates power with an ability to dominate and control, and views the fact that some cities are more able to influence the circulation of resources through the world city network than others as fundamental to their status as world cities. Additionally, as with centrality, I adopt a specifically structural conception of the source of cities' power: each city's power is a function of its position within the world city network (see Neal and Neal, 2010).

Although multiple conceptions of both centrality and power in the world city network exist, there appears to be consensus that these two concepts are closely related. More specifically, it is generally assumed that cities occupying central positions in the world city network—positions that facilitate the concentration of resources in, or diffusion of resources from, the city—are more powerful. Those cities that are densely integrated into the intercity economic, political or social flows (i.e. centrality) enjoy access to concentrated pools of resources and the ability to diffuse those resources widely, which in turn provides opportunities to exercise control over them (i.e. power). Thus, in most discussions of world cities and the world city network, centrality and power are treated as equivalent, or at least causally linked: power is derived from a central network position. The conflation of centrality and power is clear in theoretical discussions. For example, Allen argues that

> powerful cities ... stand at the intersections, so to speak, of all that matters in global economic terms (Allen, 2009, p. 187).

Thus, he connects power to the extent to which a city lies at the centre of several converging resource flows. Similarly, Boschken (2008, pp. 8–9) describes centrality as "based in part on the city's role as a node of power and connectivity". These concepts are often used interchangeably in empirical analyses as well. Alderson and Beckfield (2004, p. 822), for example, note that in examining corporate networks "we assess the power of world cities in light of three measures of point centrality" (see also Alderson *et al.*, 2010). Others also follow this approach, assessing power in light of other measures of centrality applied to different data, including flow centrality in office networks (Wall and van der Knaap, forthcoming) and eigenvector centrality in airline networks (Mahutga *et al.*, 2010). Similarly, in analyses of the interlocking branch office networks, a single measure called 'network connectivity' is used in some cases to measure cities' centrality (Beaverstock *et al.*, 2002) and in other cases to measure their power (Taylor, Walker *et al.*, 2002).

However, theories of social exchange have questioned the relationship between centrality and power. Emerson (1962) argued that power derives not simply from one's having a large number of relationships (i.e. being central), but specifically from having relationships with dependent others. Drawing on these ideas, Cook *et al.* (1983) found that, when actors are engaged in economic exchange, those whose exchange partners are dependent upon them (i.e. who were in positions of power) had more opportunities to control and influence exchanges than did those who merely had a large number of opportunities to exchange (i.e. who were in positions of centrality). That is, central actors may enjoy many opportunities to exchange resources, but they have relatively little opportunity to exercise power over those exchanges. In contrast, powerful actors may have few opportunities to exchange, but they exercise a great deal of influence over those opportunities that do exist. This finding suggests that positions of centrality are distinct from positions of power and have different consequences.

Before turning to the question of whether centrality and power should be treated as conceptually and empirically distinct in investigations of world cities, it is useful to consider how cities' centrality has actually been measured in past studies. The earliest studies of cities' centrality did not directly examine position within a network of cities, but rather used cities' internal features as a proxy indicator of centrality: comprehensive political-cultural-financial indices (Hall, 1966; Reed, 1981), counts of headquarters and corporate service firms (Friedmann, 1986; Sassen, 1991) and even occurrences of major spectacles like the Olympics or the 1995 Rolling Stones World Tour (Short *et al.*, 1996). Hierarchical rankings of cities based on these features were assumed to mirror cities' centrality in an unobserved intercity network because they indicate the consequences of such positions of centrality. This approach is problematic, however, because it risks an inherent circularity: the presumed effect of centrality in the world city network is used as an indicator of centrality itself.

Among those empirical studies that directly examine the world city network, the most widely employed measure of centrality involves counting a city's total number of linkages. In the social network analysis literature, this is known as degree centrality (Freeman, 1978/79), but other labels have been applied in studies of world cities, including interlock connection, nodal connection, situational status (Taylor, 2001) and global connectivity (Taylor, Catalano and Walker, 2002). This approach has been used to measure the extensiveness of cities' linkages in world city networks based on the interlocking branch office networks of advanced producer service firms (Taylor, Walker *et al.*, 2002), corporate headquarters and subsidiary relations (Alderson and Beckfield, 2004; Alderson *et al.*, 2010), and air traffic (Ma and Timberlake, 2008). In each case, this measure of centrality is interpreted as an indicator of power and thus the two concepts are treated as both conceptually and empirically equivalent. For example, Ma and Timberlake argue that

> one of the most effective measures of network members' relative centrality or power potential is their degree: the number of ties from and/or to others (Ma and Timberlake, 2008, p. 26).

While degree centrality offers a straightforward way of measuring the extent to which cities' are highly connected, two conceptual challenges arise. First, using a single measure to assess both cities' centrality and their powerfulness does not allow the possibility for these two characteristics of cities' position in the world city network to be distinct; it ignores the possibility that some cities are central, while others are powerful.[3] Secondly, simply counting up a city's total number of connections in the network implicitly assumes that each connection is equally valuable, when in fact some connections (for example, to New York) may be more valuable than others (for example, to small, local towns).

A limited number of studies have used more sophisticated measures of centrality known as closeness and betweenness (Alderson and Beckfield, 2004; Alderson *et al.*, 2010; Neal, 2008). Closeness centrality captures the extent to which a city is directly connected to other cities in the network or separated from them by only short indirect linkages, reflecting the notion that both direct and indirect linkages contribute to a city's centrality and to opportunities for capital accumulation or innovation diffusion. Betweenness centrality focuses on the extent to which a city serves as an intermediary that facilitates the flow of resources between other cities in the network, reflecting the notion that brokering or gatekeeping positions provide a city with a unique ability to monitor and control resource flows. While these two alternative approaches to measuring centrality provide different views of cities' positions in the world city network, their usefulness is severely limited by the fact that they can only be applied to binary networks. That is, cities' closeness and betweenness can only be assessed in networks where a relationship between cities either does or does not exist, but cannot be applied to networks where some relationships are known to be stronger than others. Measures of centrality based on eigenvectors have also been employed (for example, Smith and Timberlake, 2001; Mahutga *et al.*, 2010), but are similarly subject to severe limitations, which are discussed in greater detail in the following section.

Measuring Centrality and Power

Much progress has been made in the empirical investigation of world city networks over the concept's long history, but these efforts remain challenged by the conceptual and methodological shortcomings of existing analytical tools. Although notions of cities' centrality and power are widely used, these concepts are often left ambiguous or treated interchangeably, and are measured with instruments that do not always match the theoretical ideas they are intended to assess. In this section, I propose new conceptions of centrality and power in the world city network, with accompanying measurement tools, that aim to overcome these difficulties.

Figure 1 depicts two possible city networks, where circles represent cities and lines represent resource flows between them. While these two networks have very different structures, the focal city identified by the Black circle has the same degree centrality (i.e. the same number of direct connections: three) in both cases. Similarly, the focal city is the most central city in both networks when using closeness and betweenness measures of centrality. Thus, for the set of three most commonly used measures of centrality—degree, closeness and betweenness (Freeman, 1978/79)—these two networks and the focal city's position within them are virtually indistinguishable. It is important to consider, however, whether there are differences between network A and network B in the focal city's role as a site of resource concentration and diffusion (i.e. its centrality) and in its role in controlling the flow of resources (i.e. its power).

Turning first to centrality, it is clear that the focal city enjoys the same number of direct connections in both networks. The key difference is that these connections are more valuable in network A because they provide indirect access to still more cities, while in network B they are 'dead ends'. This logic is closely connected to Bourdieu's notions of social capital depending not only

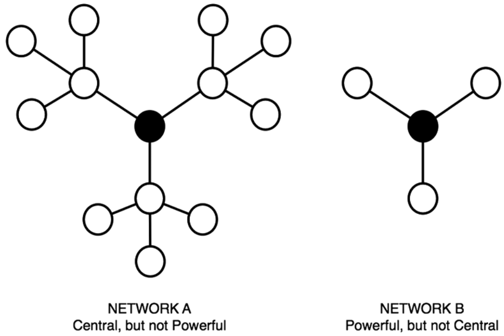

Figure 1. Two hypothetical world city networks.

> on the size of the network of connections [one] can effectively mobilize [but also] on the volume of the capital (economic, cultural, or symbolic) possessed in his own right by each of those to whom [one] is connected (Bourdieu, 1986, p. 249).

Thus, while a focus on only direct connections suggests that the focal city is equally central in these two networks, taking a wider view reveals that it is better positioned in network A because it is not merely well connected itself, but is well connected to others who are also well connected. Because this conception of centrality depends not only on a city's own connections, but also on the centrality of the other cities to which it is connected, I call it *recursive centrality*.

Because such a position of recursive centrality increases opportunities for the concentration of resources from many sources or the diffusion of resources to many sources, it may seem reasonable to assume that a recursively central city is quite powerful. However, experimental research on agents' ability to control the flow of resources in exchange settings has demonstrated that centrality does not automatically translate into power (Cook *et al.*, 1983). While the focal city in network A has direct and indirect access to resources from a number of sources, so too do the cities to which it is connected. Thus, the focal city lacks the ability to control or influence resource exchanges with its exchange partners. These partners have alternatives and thus they can ignore the actions or demands of the focal city. In contrast, although the focal city in network B has access to resources from a more limited pool of contacts (i.e. it is not recursively central), it has significant bargaining and negotiating influence over its exchange partners because it is their only source for capital, information and other valuable commodities. These partners have no alternatives and thus cannot ignore the focal city's demands. Allen touched on the advantage of such a position, noting that the importance of such cities as New York and Tokyo stems

> from the fact that the world of banking and finance seems to have little choice other than to go through the financial districts of those cities (Allen, 1999, p. 187).

This logic is also closely connected to social exchange theory, which views power as a type of relationship in which one agent is able to dominate others because these others have limited alternatives (Emerson, 1962). Because this conception of power depends not only on a city's own connections, but also on the connections (or, indeed, lack thereof) of the cities to which it is connected, I label it *recursive power*.

These recursive conceptions of centrality and power offer two significant conceptual advantages over existing approaches. First, they do not simply focus on a city's own connections, treating each as equally useful, but take a broader view of the world city network's structure to consider direct connections as well as the status of those contacts. Secondly, they distinguish centrality and power as potentially different features of a city's position within a network. In network A, the focal city is central but not particularly powerful, while in network B, the focal city is powerful but not particularly central. Differentiating these two characteristics of network position reveals that structural arrangements facilitating resource accumulation or diffusion do not necessarily also facilitate resource control, and vice versa. Some cities may have structural opportunities to become sites of large concentrations of resources or efficiently to diffuse resources throughout the rest of the network, but little ability to control their flow. In contrast, others may have structural opportunities to control the flow of resources, but a limited capacity to accumulate or disseminate them.

These simple networks help to illustrate the recursive conceptions of centrality and power. However, to be useful in empirical investigations of world city networks, these concepts must be accompanied by practical measurement methodologies. If the structure of a world city network is represented in a symmetrical matrix **R**, where each entry R_{ij} contains the strength of the connection between cities i and j, then the recursive centrality (RC_i) and recursive power (RP_i) of city i can be computed as

$$RC_i = \sum_j R_{ij} \times DC_j \tag{1}$$

$$RP_i = \sum_j \frac{R_{ij}}{DC_j} \tag{2}$$

where, DC_j is the degree centrality of city j. The first equation, used to compute recursive centrality, sums the total number (or strength) of city i's connections, weighting each one by the degree centrality of the city to which it is connected. The second equation, used to compute recursive power, performs the same operation but weights each connection by the contact's *inverse* degree centrality, thus capturing the extent to which city i is able to dominate (i.e. is the sole exchange partner for) city j (Neal and Neal, 2010). These measures can be computed using the <centpow> command in STATA, which has been written to accompany this paper; it can be downloaded by typing 'findit centpow' in the STATA command line. Applying these to the hypothetical networks in Figure 1, the focal city in network A has a high recursive centrality score (9), but a low recursive power score (0.75). In contrast, the focal city in network B has a relatively lower recursive centrality score (3), but a relatively higher recursive power score (3). These differences highlight the differing positions of these two focal cities, despite their equal degree centrality scores.

The logic underlying these proposed conceptions of centrality and power is closely related to two existing measures: eigenvector centrality (Bonacich, 1972) and beta centrality (Bonacich, 1987).[4] Although these have been applied in a limited number of world city network studies (Smith and Timberlake, 2001; Choi *et al.*, 2006; Mahutga *et al.*, 2010), their computation is complex, involving an analysis of the network matrix's eigenvectors. Additionally, their usefulness in examining world city networks is limited by two important constraints that are often overlooked. First, they cannot be applied to networks that contain clustering or cliques, which are common in world city networks (Derudder *et al.*, 2003; Derudder and Taylor, 2005). Secondly, they often do not yield useful results when applied to networks that are large (for example, 3692 cities in Alderson and Beckfield, 2004) or contain many strong linkages (for example, London's degree centrality is 63 399 in Taylor, Catalano and Walker, 2002). The mathematical complexity of eigenvector centrality (Bonacich, 1972) and beta centrality (Bonacich, 1987) places a detailed discussion of their computation and properties beyond the scope of this paper, but these limitations are considered further in the following section, in the context of the analysis of specific world city networks where they arise.

Applying Recursive Centrality and Power

Friedmann's 'Basing Points' Network

The world city network described by Friedmann (1986), while intended only as a heuristic rather than explanatory model, offers an opportunity to illustrate the proposed recursive conceptions of centrality and power in a relatively simple and well-known context (see Figure 2). Table 1 lists each city's score using the traditional degree centrality measure, as well as the recursive centrality and recursive power measures already described. Eigenvector-based measures including eigenvector centrality (Bonacich, 1972) and beta centrality (Bonacich, 1987) are not appropriate because the network's second eigenvalue ($\lambda_2 = 3.45$) is relatively large compared with its first eigenvalue ($\lambda_1 = 4.59$). This mathematical property typically occurs in networks where clustering or cliqueishness is present. In this case, regional clusters of Asian, North American and European cities are clearly visible. Using such measures in clustered networks can yield results that focus only on the largest cluster, and is akin to examining only the first factor in a factor analysis even if subsequent factors were also found to be important.

Comparing the results of the recursive measures with those of the more traditional degree centrality measure, it is clear that the recursive measures provide finer-grained distinctions among cities. Using degree centrality, many cities are tied with the same scores; among the 25 cities in the network, there are only seven unique degree centrality scores. This suggests, for example, that Los Angeles, Tokyo and Singapore are structurally identical because they have the same

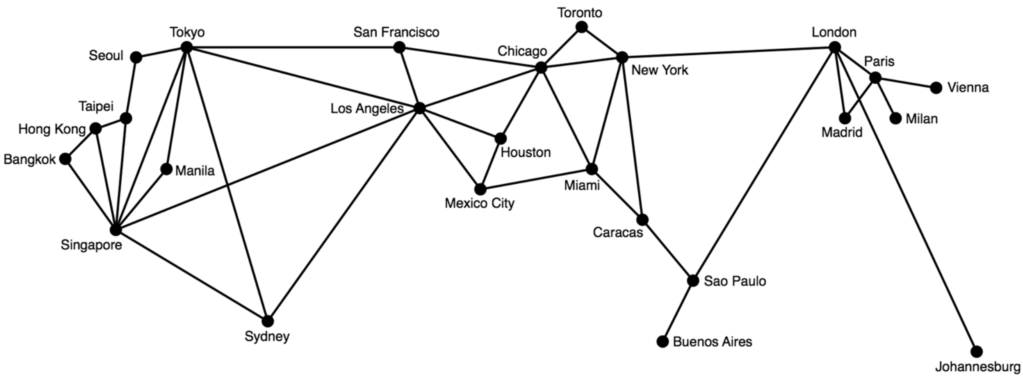

Figure 2. Friedmann's world city network.

Table 1. Comparing centrality and power among Friedmann's world cities

Degree centrality		*Recursive centrality*		*Recursive power*	
Los Angeles	1.00	Los Angeles	1.00	Paris	1.00
Tokyo	1.00	Tokyo	0.88	Singapore	0.85
Singapore	1.00	Singapore	0.82	Tokyo	0.80
Chicago	0.86	Chicago	0.76	London	0.78
New York	0.86	New York	0.73	New York	0.67
London	0.71	Rio de Janiero	0.70	Rio de Janiero	0.65
Rio de Janiero	0.71	Sydney	0.64	Chicago	0.64
Mexico City	0.57	San Francisco	0.61	Los Angeles	0.63
Miami	0.57	Mexico City	0.58	Miami	0.40
Paris	0.57	London	0.55	Hong Kong	0.36
Hong Kong	0.43	Miami	0.55	Taipei	0.36
Houston	0.43	Houston	0.52	Mexico City	0.34
San Francisco	0.43	Manila	0.42	Houston	0.21
Sydney	0.43	Hong Kong	0.36	Bangkok	0.18
Taipei	0.43	Taipei	0.36	Seoul	0.18
Bangkok	0.29	Toronto	0.36	Madrid	0.17
Caracas	0.29	Bangkok	0.30	San Francisco	0.17
Madrid	0.29	Caracas	0.30	Sydney	0.16
Manila	0.29	Seoul	0.30	Caracas	0.15
Seoul	0.29	Madrid	0.27	Toronto	0.12
Toronto	0.29	Paris	0.27	Manila	0.11
Buenos Aires	0.14	Buenos Aires	0.15	Milan	0.09
Johannesburg	0.14	Johannesburg	0.15	Vienna	0.09
Milan	0.14	Milan	0.12	Buenos Aires	0.07
Vienna	0.14	Vienna	0.12	Johannesburg	0.07

Notes: Ties are listed in alphabetical order. Scores are rescaled with a maximum value of 1.

number of linkages to other cities. In contrast, using recursive centrality and power, there are fewer cities with tied scores; among the 25 cities, there are 17 unique recursive centrality scores and 20 unique recursive power scores. Thus, the recursive measures allow cities' positions in the network to be distinguished more effectively. For example, the recursive centrality measure reveals that although Los Angeles, Tokyo and Singapore may have the same number of direct linkages, Los Angeles is likely to enjoy greater concentrations of resources and greater ability to disseminate innovations than the other two.

In addition to allowing finer-grained distinctions among cities' network positions, the recursive measures also allow cities' centrality and power to be considered separately. Using degree centrality, Paris appears to be moderately central (0.57), which may be interpreted as evidence of second-tier world city status. However, a more complete picture of Paris' world city status emerges when centrality and power are treated as distinct concepts. Paris has a relatively low recursive centrality score (0.27), but has the highest recursive power score in the network (1.0). These results might suggest that, while Paris may not be a hub of capital accumulation, it is a centre of command-and-control, serving as an intermediary that connects other European cities (such as Milan, Vienna) to the world. That is, to view Paris as a second-tier world city obscures its more nuanced role as a minor site of flow concentration but a major site of flow influence. A similar but reversed story emerges in the case of Sydney which, like Paris, appears moderately central using degree centrality (0.43) but, unlike Paris, is revealed to be highly central (0.64) and minimally powerful (0.16) when the recursive measures are used. The cases of Sydney and Paris mirror the cases of the focal cities in Figure 1's network A and network B. Despite both cities having similar degree centrality, Sydney's position in the Friedmann network closely resembles the 'central but not powerful' focal city in network A, while Paris' position more closely resembles the 'powerful but not central' focal city in network B.

The Internet Backbone Network

Although applying the proposed recursive centrality and power measures to Friedmann's hypothetical world city network is instructive, it is also important to consider how these measures work when applied to 'real' data. Examining the network of Internet backbone connections among cities—the physical infrastructure that digitally links cities to one another—offers an opportunity to examine directly one actual world city network. Choi *et al.* (2006) compiled a network of 82 international cities from two annual reports of Internet geography (Telegeography, 2002a, 2002b) and have kindly provided their data for this paper. Unlike the Friedmann network already considered, which merely indicated the presence or absence of a relationship, this network captures the capacity for information flow between pairs of cities, measured as megabits per second (Mbps) of bandwidth.

Like all networks among cities, the organisation of the Internet's physical infrastructure is the result of some combination of political forces and a cost-minimising logic of growth. Yet, whatever the causes of its current structure, it remains the principal method for moving information between cities and thus is of critical importance for economic, social, political and cultural activities. Beyond its role in structuring a range of intercity transactions, I examine this Internet infrastructure network data for two additional reasons. First, it is relational data that directly measure relationships between pairs of cities, rather than the more common attribute data that measure characteristics of individual cities such as the presence advanced producer service firms (Taylor, Catalano and Walker, 2002) or multinational headquarters data (Alderson and Beckfield, 2004; Alderson *et al.*, 2010; for a critique, see Nordlund, 2004; Neal, 2010a). Secondly, it was originally analysed in a highly cited study of world city networks (Choi *et al.*, 2006) using eigenvector-based measures of centrality and power that are conceptually similar to those proposed earlier, but which were methodologically inappropriate. Thus, the discussion that follows might be viewed as a re-analysis that provides a more robust assessment of cities' centrality and power.

In this case, eigenvector-based measures like eigenvector centrality (Bonacich, 1972) and beta centrality (Bonacich, 1987) are not appropriate because the network's largest eigenvalue ($\lambda_1 = 178\,231.55$) is too large. This typically occurs in networks with many nodes (for example, cities) or when the connections between some pairs of nodes are strong relative to other pairs. For example, in this network, the bandwidth connection between New York and London is 96 599 Mbps while the connection between Manila and Jakarta is only 10 Mbps. Using eigenvector-based measures in such cases, although technically possible, yields centrality and power scores that are equal or nearly equal to each other and to ordinary degree centrality. As a result, they offer no additional information about network position.

Plotting the 82 cities by both their recursive centrality and recursive power in this network, Figure 3 illustrates that centrality and power are distinct characteristics of cities' network positions. This suggests that positional status in the world city network is not a unidimensional phenomenon ranging from highly central and powerful world cities to peripheral and powerless lower-tier cities. Instead, network status is better understood as a multidimensional phenomenon where centrality and power are independent and combine in various ways to constitute distinct types of world cities (see Guimera *et al.*, 2005).

The most obvious examples of world cities—London and New York—lie at one extreme. Indicated by their position in the upper-right corner of Figure 3, these cities occupy positions in the Internet backbone network that make them both highly central and highly powerful. In this case, recursive centrality indicates that these cities have many high bandwidth connections to cities that themselves also have many high bandwidth connections. Such a position allows large amounts of information, coming both from direct connections as well as more distant indirect connections, to converge in a single location and allows large amounts of information to be diffused very efficiently from London and New York to the rest of the world. This provides the actors in these cities (for example, multinational firms, political leaders, cultural organisations, social movements) with greater opportunities to strategise and innovate. In addition, however, recursive power indicates that these cities also have high bandwidth connections to cities that have few other high bandwidth connections. This position of power allows these cities to control the flow of information to certain parts of the network because they act as the sole gateways through which some cities gain access to the global Internet backbone. By simultaneously occupying a position of centrality and a position of power in the world city network, cities like London and New York capture the structural advantages of both resource accumulation/diffusion and resource control, and thus stand apart as *quintessential world cities*.

However, positions of centrality and power are not always found together. As Figure 3 illustrates, a second group of cities—Paris, Amsterdam, Washington, Brussels and Chicago—occupy highly central positions in the network, but do not occupy positions that afford them significant amounts of power. By occupying highly central positions, these cities are likely to be resource rich, with structural opportunities to accumulate and diffuse the commodities that flow through the network (in this case, information). They are not, however, likely to have much influence over the flow of those resources elsewhere in the system and thus little ability to control the

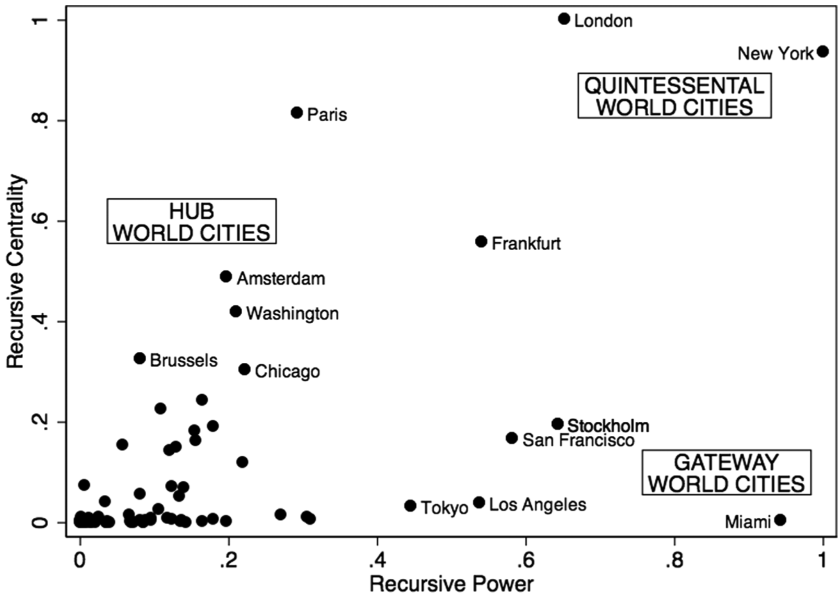

Figure 3. Comparing recursive centrality and power in the Internet backbone network.

activities in other cities. Quite different from the quintessential world cities of London and New York, these 'central but not powerful' places are a unique type of world city characterised by their role as *hubs*. Such places are likely sites of innovation because they benefit from the high concentrations of capital and the ability to disseminate new information that is necessary for such activities. In this case, the role of hubs as centres of national (for example, Paris, Washington) and transnational (for example, Brussels) government also highlights the ability of cities in central positions efficiently to communicate policy and diplomatic messages to wide audiences.

A third group of cities—Miami, Stockholm, San Francisco, Los Angeles and Tokyo—are the mirror image of hubs, occupying positions of power but not of centrality. By occupying positions of power, these cities are likely to be highly influential, with structural opportunities to function as gatekeepers that can mediate or broker other cities' access to the resources flowing through the network. They are not, however, likely to be sites of significant resource concentrations or particularly effective at diffusing resources through the network. Quite different from both quintessential and hub world cities, these 'powerful but not central' places are characterised by their role as *gateways*. Such places are likely to be sites of instrumental and co-ordinative activities (for example, banking, advertising and consulting) that facilitate the more primary activities found in hub world cities. In this case, because the Internet backbone network is constituted by physical infrastructure, the most powerful cities are located at the geographical edges, serving as the principal entry points for their respective continents. However, in other less physically grounded networks such as the branch office networks of advanced producer service firms, the spatial organisation of powerful gateway cities and central hub cities may be less patterned.

Discussion and Conclusion

By examining both hypothetical and observed world city networks, these analyses suggest that centrality and power are distinct characteristics of world cities that derive from distinct structural patterns of linkages. Occupying a position of centrality in the world city network does not automatically translate into structural opportunities to exercise power. To differentiate effectively positions of centrality from positions of power requires moving beyond relatively simple measures such as degree centrality. In addition, empirical analysis of the world city network requires accounting for the differing strength of intercity linkages, which limits the usefulness of closeness and betweenness measures, and attending to the mathematical properties of highly sophisticated network indices, which limits the usefulness of eigenvector-based measures. The proposed measures of recursive centrality and recursive power offer a practical solution to these issues. These measures effectively differentiate centrality from power in theoretically informed ways, are computationally simple and can be applied to networks where some linkages vary in strength.

More than simply a methodological innovation, however, these analyses have challenged the conception of world cities' status in networks as a unidimensional, hierarchical phenomenon. Rather, they suggest that positional status in the world city network is a multidimensional phenomenon that has implications for the roles that cities play in the world system. First, quintessential world cities simultaneously occupy positions of centrality and power, and serve as the principal outposts of economic, political and social globalisation. Secondly, hub world cities occupy positions of centrality but not power, and serve as sites for resource concentration and diffusion where innovation and investment activities are supported. Finally, gateway world cities occupy positions of power but not centrality, and serve as gatekeepers that gain influence through their ability to broker and mediate other cities' access to the rest of the network. This typology differs from previous multidimensional classifications of cities that have focused on combinations of city attributes (for example, Boschken, 2008) because it links cities' roles directly to the structural properties of the world city network. This is a major strength because it paves the way for future studies to examine how the structurally defined roles of quintessential, hub and gateway city are associated with such attributes as firm location or demographic diversity without undue circularity.

Conceptualising centrality and power in the proposed recursive manner, where a city's status depends not only on its own connections but also on the connectivity its contacts, also has implications for understanding changes in the structure of the world city network. A given city's status in the global arena depends in part on the number and strength of external linkages it maintains. However, equally important are the number and strength of external linkages maintained by those cities to which it is connected. Thus, whether a city's status rises or falls over time depends not on its own internal features, nor on its own network, but on the structure of the entire world city network. This more global understanding of world city status suggests that purposive attempts to enhance a city's global status may be quite difficult and, indeed, may lie outside the reach of a city's own leaders. Nonetheless, for cities seeking a more global identity, urban leaders must look beyond simply forging newer and stronger external linkages, and focus on forging strategic linkages. Enhancing resource concentration potential (i.e. centrality) requires new connections to well connected places, while enhancing command-and-control potential (i.e. power) requires new connections to poorly connected places.

Yet, just as centrality and power may occur independently, they are also likely to occur in different combinations based on the substance of the network in question. In the analysis presented earlier, the most powerful cities were those located at the edges of continents, because they were geographically convenient gateways for the Internet's physical infrastructure. However, examining other types of network that map the flow of different resources (for example, foreign direct investment, migration) would be likely to reveal that the same cities play unique roles in other contexts. The two earlier analyses illustrate one such case: Paris is powerful but not central in Friedmann's economically focused network, yet it is central but not powerful in a communication infrastructure network. Thus, cities may play the role of a gateway world city in some domains, while playing the role of a hub world city in others. The character and status of any given city in the global arena, therefore, is the result of its varying levels of centrality and power in each of several networks. Indeed, the two measures developed in this paper can be applied to world city networks defined to capture not only exchanges of an economic nature, but also cultural, political and social flows. Future research should focus not only on how centrality and power differ in economic contexts, but how they differ in these other global city arenas as well.

Notions of centrality and power are ubiquitous in discussions of cities' positions within world city networks. Frequently, these concepts are treated as indistinct and are measured using conceptually simple or methodological inappropriate instruments. However, centrality and power are conceptually distinct and have unique consequences for cities, and therefore should be differentiated in empirical investigations of world city networks. The proposed measures of recursive centrality and recursive power offer a promising approach that provides a more refined and theoretically informed view of cities' network positions, while also overcoming some of the methodological limitations of existing approaches. Together, they more accurately capture the multidimensionality of world city status where cities play different roles within and across different types of network.

Notes

1. Any discussion of urban systems risks reifying cities and treating them as actors. The variety of forms that urban networks may take yields an equal variety of actors that constitute and maintain the networks. In intercity transport and communication networks, individuals (such as passengers, callers) are the true actors. In command-and-control networks like those discussed by Alderson and Beckfield (2004), firms (given agency by executives) are the actors. Finally, in political networks like those forged by sister-city relationships, the cities (given agency by political leaders) are the actors. For the sake of simplicity, cities are discussed as the actors responsible for the network, but it is recognised that the actual actor depends on the type of network and the conceptual level of analysis.
2. This paper aims to clarify methods of analysing world city networks, specifically by developing more robust measurements of cities' centrality and power based on their positions within such networks. Derudder (2006) has noted a related need for clarity in the data used to define the networks themselves. He argues that there are two broad empirical approaches, each of which implies a set of (often unstated) theoretical assumptions: a corporate organisation approach that focuses on producer service firms or multinational corporations and an infrastructure approach that focuses on the built structures that facilitate communication and transport. Although this paper and Derudder's tackle different issues, together they highlight that empirical world city research could benefit from more careful attention to issues of both data and their analysis.
3. Notably, Alderson and Beckfield (2004) analysed a network of directed relationships, which permitted the computation of two types of degree centrality: in-degree centrality, which counts the number of inbound linkages, and out-degree centrality, which counts the number of outbound linkages. Although in- and out-degree centrality are distinct measures, they are nonetheless still both measures of centrality, and not of power.

4. Eigenvector centrality is a measure of centrality only. In contrast, the operation of beta centrality, which is also sometimes called Bonacich Power, depends on the value of the β parameter selected by the researcher. It can be used to measure either centrality (when $\beta > 0$) or power (when $\beta < 0$).

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