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Structural Determinism in the Interlocking World City Network

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Taylor's interlocking specification of the world city network has offered researchers a theoretically informed way to measure the world city network using readily available firm location data. However, the number and size of firms that are viewed as linking cities to one another impose a form of structural determinism on the world city network. Specifically, when a relatively small number of firms is used to define a network among a relatively large set of cities, or when only larger firms are used, this approach is unable to reveal a wide range of structures features that may actually be present in the world city network it is intended to measure. Through a series of examples, I demonstrate how specific features of firm location data predetermine the structure, number and size of cliques, and density of world city networks derived using the interlocking approach. Concluding comments discuss the implications of this structural determinism by focusing on the case of the commonly used Globalization and World Cities data set 11, offer some suggestions concerning how the interlocking approach can be employed while avoiding structural determinism, and identify some alternative approaches to mapping the world city network.

Introduction

A decade ago, Taylor (2001) devised a specification of the world city network that aimed to provide a theoretically grounded conceptualization of the network as well as a methodology for measuring it. As a conceptualization, it calls attention to cities as the nodes in the world city network but highlights that they are linked through a critical subnodal level of advanced producer service firms that "are the prime actors in world city network formation" (p. 181). As a methodology, it offers researchers a way to examine the world city network despite the lack of genuine flow data that had previously held back relational studies of urban processes. Since its initial appearance, Taylor's interlocking approach has become one of the *de facto* methods for conceptualizing and measuring linkages in city networks, along with approaches based on corporate headquarters and subsidiary locations (e.g., Alderson and Beckfield 2004) and on transportation (e.g., Neal 2010). Research about the world city network adopting this approach has appeared in journals (e.g., Taylor, Catalano, and Walker 2002), books (e.g., Taylor 2004; Taylor, Hoyler, and Verbruggen 2010), and institute reports (e.g., Taylor and Lang 2005).[1]

The interlocking specification of the world city network has advanced research on the topic in both substantive and methodological directions. However, in this article, I argue that it is subject to a significant, and previously unrecognized, limitation. The number and size of the firms (i.e., the number of cities in which firms maintain a presence) or other organizations, which are viewed as linking cities at the subnodal level,

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impose a form of structural determinism on the world city network. Specifically, when a relatively small number of firms is used to define a network among a relatively large set of cities, or when only larger firms are used, this approach always yields a world city network that is cliquish and dense, and that cannot have ring, star, or chain structures. This outcome is particularly problematic because in the most common application of the interlocking approach, the number of cities (315) greatly exceeds the number of firms (100), and the firms are relatively large (Taylor, Catalano, and Walker 2002), calling into question conclusions drawn from these data.

I begin this article by first describing Taylor's (2001) interlocking specification of the world city network. I then demonstrate through a series of examples how this interlocking approach can structurally predetermine features of the resulting world city network. Next, I consider the practical implications of this structural determinism when the interlocking approach is applied to the widely used Globalization and World Cities (GaWC) data set 11. Finally, I conclude by offering some suggestions on avoiding structural determinism in measuring world city networks.

The interlocking world city network

For decades, geographers and others have hypothesized the existence of a global urban network in which the "linkages make it possible to arrange world cities into a complex spatial hierarchy" (Friedmann 1986, p. 71). However, empirical investigations of such a world city network were hampered by a lack of suitable data. Taylor's (2001) interlocking specification of the world city network aimed to offer a solution by calling attention to a prior conceptual and theoretical question: can cities be network actors? Although cities may have some agency through their local administrations, he argued that cities are the sites of action but not the key actors themselves. Instead, transnational firms are the prime actors in the processes that give rise to world cities as command-and-control centers.[2] Thus, while cities are the nodes in a world city network, they are linked to one another not through their own actions but rather through the actions of the transnational firms for which they serve as operating locations. Transnational firms maintain offices in many different cities throughout the world to provide clients with superior service and to project a global image. When two cities are home to branches of the same firm, information and influence are assumed to flow between them. Following this logic, the interlocking approach to the world city network defines two cities as linked in the network to the extent that they are home to offices of the same firms.

In practice, the interlocking network approach begins by arranging firm location data in a c-by-f firm location matrix, $\mathbf{F}$, where c is the number of cities in the network under investigation, and f is the number of firms that give rise to the network. Each entry in this matrix, $\mathbf{F}_{ij}$, indicates whether firm j maintains an office in city i. These entries may be binary, indicating the presence or absence of a firm in each city, or they may be assigned values that represent the size or importance of a firm's office in a given city, following the logic that "the larger the office the more connections there are with other offices in a firm's network" (Taylor 2001, p. 186). The firm location matrix, $\mathbf{F}$, then is transformed into a c-by-c city network matrix, $\mathbf{C}$, that captures relationships between each pair of cities. Taylor (2001) defines each entry in $\mathbf{C}$ using

$$C_{ab} = \sum_j F_{aj} \times F_{bj}, \tag{1}$$

where F_{aj} indicates the presence of firm j in city a and C_{ab} indicates the extent to which cities a and b contain the offices of the same firms. He was seemingly unaware in 2001 that this method for obtaining a one-mode network (e.g., city-to-city) from two-mode data (e.g., city-by-firm) had been used for decades in graph theory (Breiger 1974; Neal 2008) and can be expressed more simply as

$$\mathbf{C} = \mathbf{F} \times \mathbf{F}' \tag{2}$$

where $\mathbf{F}'$ is the transpose of $\mathbf{F}$.

The hypothetical example depicted in Fig. 1A serves to illustrate the approach. In this example, two firms are used to construct a network among four world cities. The firm location matrix indicates that Firm

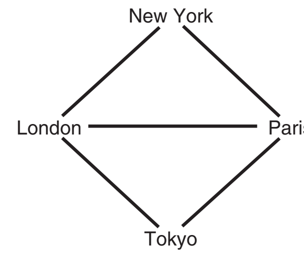
(a)

	Firm A	Firm B
New York	1	0
London	1	1
Paris	1	1
Tokyo	0	1

Firm location matrix, **F**

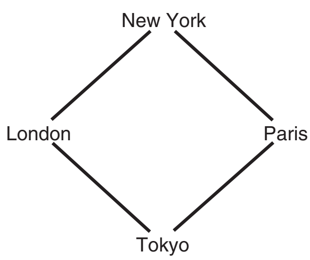
	New York	London	Paris	Tokyo
New York	1	1	1	0
London	1	2	2	1
Paris	1	2	2	1
Tokyo	0	1	1	1

City network matrix, **C**



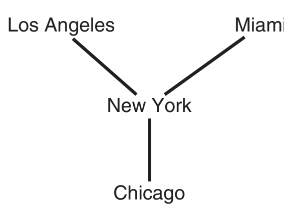
World city network

(b)



	Firm A	Firm B	Firm C	Firm D
New York	1	0	0	1
London	1	1	0	0
Paris	0	1	1	0
Tokyo	0	0	1	1

(c)



	Firm A	Firm B	Firm C
New York	1	1	1
Chicago	1	0	0
Los Angeles	0	1	0
Miami	0	0	1

Figure 1. Illustrations of interlocking world city networks. (a) Constructing an interlocking world city network. (b) Measuring a ring-structured network using the interlocking approach. (c) Measuring a star-structured network using the interlocking approach.

A operates offices in New York, London, and Paris, but not in Tokyo. Similarly, Firm B operates offices in London, Paris, and Tokyo, but not in New York. The city network matrix is obtained by applying equation (1) to each cell in **F** individually or by applying equation (2) to **F** as a whole. A "1" appears in London's row and New York's column, indicating that these two cities are linked in the network, in this case because they both contain offices of Firm A. A "0" appears in Tokyo's row and New York's column, indicating that these two cities are not linked in the network because they do not contain offices for any of the same firms. A "2" appears in London's row and Paris's column, indicating that these two cities are strongly linked in the network, in this case because they both host offices of Firms A and B.

Currently, most network analyses require that linkages be coded as simply present or absent (i.e., binary) rather than as stronger or weaker (i.e., valued). Throughout this article, I make no assumptions about how strong a linkage must be to "count" and therefore simply consider linkages of any strength as present.[3] The city network matrix can be represented in the form of a sociogram, as shown in Fig. 1A, to depict graphically the structure of the world city network. Although a wide range of techniques exists that may be employed to analyze a city network at this stage, this article does not address how a city network may be analyzed once it has been constructed; rather, it addresses the implications of using the interlocking approach to construct a network.

Structural determinism

As a conceptualization, Taylor's (2001) interlocking specification of the world city network importantly calls attention to the critical role of firms as the key economic and social actors in linking cities in a network. However, as a methodology, an important question remains: is Taylor's interlocking specification of the world city network valid? For a measurement methodology to be useful, it must be valid; that is, it must be able to measure the real-world phenomenon it is intended to measure. Thus, the interlocking approach is a useful methodology only if it can produce a network that is a faithful representation of the actual but unobserved world city network it is intended to measure, within the limits of measurement and sampling error. In this section, I demonstrate that although the interlocking approach can do so in principle, it often lacks validity in practice because the features of the world city networks it produces are structurally predetermined by features of the firm location data.

Fig. 1B depicts a possible network among four world cities. If we suppose that this is the actual but unobserved network to be measured using the interlocking approach, one important question is: what properties must the firm location matrix have to enable a researcher to measure this network? In this example, only the firm location matrix shown in Fig. 1B can produce this network.[4] One firm is necessary to establish the linkage between each pair of cities: Firm A forges the linkage between New York and London, Firm B forges the linkage between London and Paris, and so on. A firm location matrix that includes any fewer firms could not reproduce this network. This example illustrates one characteristic of the interlocking approach: *to produce a network with a ring structure, the number of firms must be equal to or greater than the number of cities*. If the firm location matrix includes more cities than firms, the network derived using the interlocking approach cannot have a ring structure. Such data could produce a ring-*like* network; for example, a network that also includes a linkage between London and Paris could be derived from just two firms (e.g., Fig. 1A), but not a network with a true ring structure.

Fig. 1C depicts another possible network among four world cities. Again, an important question arises: what properties must the firm location matrix have to enable a researcher to capture accurately such a world city network? In this example, only the firm location matrix shown in Fig. 1C can produce this network. One firm is necessary to establish the linkage between New York and each other city: Firm A links New York to Chicago, while Firm B links New York to Los Angeles, and Firm C links New York to Miami. As before, a firm location matrix that includes any fewer firms could not accurately reproduce this network. This example illustrates another characteristic of the interlocking approach: *to produce a network with a star structure, the number of firms must be equal to or greater than the number of cities minus one*. If the number of cities in a firm location matrix exceeds the number of firms by more than one, the network derived from the interlocking approach cannot have a star structure. Such data could produce a star-*like* network; for example, a network that also includes a linkage between Los Angeles and Miami could be derived from just two firms, but not a network with a true star structure. Although this example focuses on star networks, this property also extends to networks with a chain structure in which cities are linked in a linear sequence (e.g., New York–London–Paris–Tokyo).

Simple ring structures like the one in Fig. 1B may be somewhat rare today but were common structures in intercity trade networks of the past (Abu-Lughod 1989). Star structures like the one in Fig. 1C remain quite common, forming the empirical basis of core–periphery systems (Friedmann 1986; Alderson and Beckfield 2004). Similarly, chain structures are common in trade and supply-chain networks, as well as in transportation and communication infrastructure networks (Dunn 1970; Smith and Timberlake 1995). Many of the more complex network structures hypothesized to exist among world cities are built from simple structures overlapping in various combinations.

In addition to affecting the types of network structures that can be observed, firm location data also impact the cliquishness and density of derived networks. When using the interlocking approach to derive a world city network from firm location data, each firm that appears in the firm location matrix generates every possible pairwise linkage among the set of cities in which it operates an office. For example, a firm operating in three cities—X, Y, and Z—generates three linkages in the network: XY, XZ, and YZ. Similarly, a firm operating in four cities—W, X, Y, and Z—generates six linkages: WX, WY, WZ, XY, XZ, and YZ. More generally, the number of linkages generated by a single firm is a combinatorial, not a linear, function of the number of cities in which it operates. The large number of linkages generated by each firm joins its host cities into a maximally dense, maximally connected clique (Latapy, Magnien, and Del Vecchio 2008).[5]

From the way that firms generate linkages between cities in an interlocking world city network, three additional, structurally deterministic properties of the interlocking approach can be defined. First, because at least one firm is required to generate each clique, *to produce a network with F unique cliques, the number of firms must be equal to or greater than F*. Thus, the number of firms in a firm location matrix constrains the number of cliques that can appear in the derived network. For example, a researcher using the interlocking approach to derive a world city network from the office locations of 20 firms cannot obtain a network that contains 21 or more cliques.

Second, because each firm generates a clique containing all cities in which it maintains offices, *to produce a network in which the smallest clique contains* C *cities, the smallest firm must maintain a presence in exactly* C *cities*. Thus, the size of the smallest firm in a firm location matrix, as measured by the number of cities in which it maintains a presence, constrains the size of the cliques that can appear in the derived network. For example, if the smallest firm in a firm location matrix maintains offices in five cities, a world city network derived using the interlocking approach cannot contain cliques with fewer than five members.

Third, because each firm generates every possible pairwise linkage among the cities in which it maintains a presence, *the number of cities in which the largest firm maintains a presence defines the minimum number of linkages a network can contain*. Thus, the size of the largest firm in the firm location matrix, as measured by the number of cities in which it maintains a presence, constrains the density of the derived network. Specifically, an interlocking network's minimum density is defined by

$$\text{Minimum possible density} = \frac{\left(F_{\max}^2 - F_{\max}\right)/2}{\left(C^2 - C\right)/2} \tag{3}$$

where $F_{\max}$ is the number of cities in which the largest firm maintains a presence, and C is the number of cities in the entire network. The numerator expresses the number of linkages generated by the largest firm, and the denominator expresses the total possible number of linkages in the network. Although the density of a network can normally range from zero (no possible ties present) to one (all possible ties present), the density of an interlocking network has a narrower range. For example, the density of an interlocking network derived from firm location data for four cities, in which the largest firm maintains a presence in three of these cities (e.g., Fig. 1A), can range only between 0.5 and 1. Drawing together these structurally deterministic properties, which are summarized in Table 1, Watts (2003) notes that "even a random [interlocking] network—one that has no particular structure built into it at all—will be highly clustered" (p. 128).

Table 1 Summary of the Interlocking Approach's Structural Determinism

Feature of firm location data	Structurally determined outcome in derived network
Number of cities $\geq$ Number of firms	Network cannot have a ring structure
Number of cities – 1 $\geq$ Number of firms	Network cannot have a star or chain structure
Number of firms = F	Network cannot contain more than F unique cliques
Smallest firm maintains an office in $F_{\min}$ cities	Smallest clique contains exactly $F_{\min}$ cities
Largest firm maintains an office in $F_{\max}$ cities and there are a total of C cities	Network density cannot be less than $\frac{\left(F_{\max}^2 - F_{\max}\right)/2}{\left(C^2 - C\right)/2}$

Implications for world city network research

A significant portion of research using the interlocking approach has derived a world city network from the GaWC data set 11. Thus, taking a close look at these data in light of the preceding discussion illustrates the potential risks of structural determinism when using the interlocking approach. Collected in 2000 with support from the Economic and Social Research Council, these data indicate which of 100 advanced producer service firms maintain an office in each of the 315 international cities (Taylor, Catalano, and Walker 2002). Firms were included based on two criteria: (1) the provision of service in one of six sectors, including accounting, advertising, banking/finance, insurance, law, and consulting; and (2) an office presence in at least 15 of the 315 cities. Each office was assigned a score between one and five to indicate its level of service (e.g., headquarters versus small branch office) in the city. For simplicity, in this discussion, I focus only on the presence or absence of firms in cities.[6]

By applying the interlocking approach to these data, a 315-node world city network can be derived, which is intended to reflect the structure of a world city network that exists but that cannot be directly measured (Taylor, Catalano, and Walker 2002). However, for reasons previously discussed, the application of the interlocking approach to the GaWC data set 11 yields a structurally predetermined world city network. First, because the number of cities in these data (315) exceeds the number of firms (100), they cannot reveal a world city network with a ring, star, or chain structure. Thus, researchers who apply the interlocking approach to these data are committed to an a priori judgment that the world city network is not structured as a ring, star, or chain. Adopting such a position seems particularly problematic in view of theoretical claims and empirical evidence to the contrary. For example, many have argued that the forces of capital accumulation have created a star-like world city network in which there is a sharp distinction between core and peripheral cities (Friedmann 1986; Alderson and Beckfield 2004).

Second, because these data include 100 firms and the smallest among them maintains offices in 15 cities, they yield a world city network that can contain no more than 100 cliques, each of which is composed of no fewer than 15 cities. Thus, researchers who apply the interlocking approach to these data are committed to an a priori judgment that the world city network is structured by a limited number of relatively large cliques. Findings that the world city network is cliquish are unsurprising (Taylor 2004, p. 117; Derudder and Taylor 2005), arising not from an empirical discovery but from a methodological necessity (Watts 2003; Latapy, Magnien, and Del Vecchio 2008).

Third, these data indicate that the global accounting firm, KPMG, is the largest firm in the sample, maintaining a presence in 269 of the 315 sample cities. The spatial extent of KPMG's global presence ensures that the minimum possible density of the interlocking world city network derived from this data is 0.728 (see equation [3]). That is, when evaluating whether linkages in the world city network are dense or sparse, the density measure does not have a traditional zero-to-one range, but rather has a significantly narrower 0.728-to-1 range. As a result, findings that the world city network is dense or tightly knit must be interpreted with caution because large values are methodologically driven and do not necessarily reflect meaningfully dense interaction patterns.

These problems of structural determinism are not restricted to the world city network constructed from the GaWC data set 11 alone; related data sets share many of the same structurally deterministic features. For example, the GaWC data set 15 maps 22 architectural firms across 104 cities, in which the smallest firm (Ziedler Roberts Partnerships) maintains a presence in four cities, and the largest (Bovis Land Lease) a presence in 59 cities. In this case, the resulting city network cannot have a ring, star, or chain structure; can contain a maximum of 22 cliques, each with a minimum size of 4; and can have a minimum overall density of 0.32. Indeed, nearly all world city networks derived using the interlocking approach will exhibit at least some of the forms of structural determinism previously discussed.

So far, the focus of this article is on how the interlocking approach constrains a world city network's overall structure, cliquishness, and density. However, only a limited number of studies actually examine such features. Instead, the majority of analyses focus on specific cities' integration into a network. Thus, a useful consideration is whether the interlocking approach's inherent structural determinism also impacts measures of integration. The most widely used measure of integration in the interlocking world city network literature is known as connectivity (or, occasionally, global network connectivity), which is defined as the sum of a city's connections to all other cities in the given network (Taylor, Catalano, and Walker 2002). Although this definition makes the measure appear to assess cities' integration in a network of relationships with other cities, the connectivity of city c is simply a weighted count of the firms located within it, defined as

$$\text{Connectivity}_c = \sum_f \left(P_f - P_{fc}\right) \times P_{fc}, \tag{4}$$

where P_f is the total global presence of firm f, and P_{fc} is its presence in city c. This equation illustrates that a city's so-called connectivity can be computed without any data concerning its connections with any other cities. Although initially proposed as a more relationally focused, network-oriented alternative to simpler ranking measures (Taylor, Hoyler, and Verbruggen 2010), connectivity does not take into account any relational features of cities' linkages with one another and thus falls short of this goal. Instead, connectivity is simply a weighted method of counting the number of firms in a city. Because this connectivity measure is not based on a network's structure, it is not affected by the structural determinism of the interlocking approach, but it also is not a useful indicator of cities' network integration.

In contrast to connectivity, graph-theoretic measures of centrality, including closeness, betweenness, and eigenvector centrality take into account a network's structure and thus are potential alternative measures of cities' network integration. However, precisely because they take into account a network's structure, they are biased by the interlocking approach's structural determinism. First, closeness assesses the extent to which a given node is separated from all other network nodes by only a short number of paths (Freeman 1978). Because the interlocking approach always produces dense, clustered networks, cities' closeness centralities are inflated. Second, betweenness centrality assesses the extent to which a given node lies along the shortest path between two otherwise disconnected nodes (Freeman 1978). Because the interlocking approach always produces maximally connected cliques, cities' betweenness centralities are biased downward. Finally, eigenvector centrality assesses the extent to which a node is connected to other well-connected nodes but is robust only when a network exhibits a core–periphery pattern (Borgatti and Everett 2006). Because the interlocking approach can produce the star-like structure of a core–periphery pattern only under limited circumstances, cities' eigenvector centralities are often not robust.

Recommendations and conclusion

The potential for structural determinism does not necessarily warrant abandoning Taylor's (2001) interlocking specification of the world city network. This model remains an important conceptual contribution that highlights the critical role that firms play as the primary agents of world city network formation and thus offers an elegant solution to the problem of reifying cities. It can also remain a useful strategy for measuring world city networks in the face of limited data. However, the preceding discussion points to four recommendations for its future use. First, the firm location data should include at least as many firms as cities, thereby preserving the possibility that a derived network can take any structural form, including a ring, star, or chain. Second, after specifying inclusion criteria, the data should include firms that have been randomly sampled from a population, thereby allowing constraints on clique size and network density to be driven by population characteristics rather than by researchers' decisions. Third, conclusions about the structure, cliquishness, and density of a world city network derived using the interlocking approach should be interpreted with caution and should be rescaled to correct for the theoretical maxima and minima identified in this article. Finally, measures of integration or centrality must be selected carefully, ensuring that they summarize cities' relationships with one another and that they are not systematically biased by artifacts of the interlocking approach.

Admittedly, these recommendations may be a tall order, especially in a field where empirical research is already challenged by issues of data availability. Other solutions to the problem of structural determinism are available. The interlocking approach derives a one-mode city-by-city network from data that begins in two-mode firm-by-city form. However, methodologies also are available that allow researchers to examine directly two-mode data as a network (Field *et al*. 2006; Latapy, Magnien, and Del Vecchio 2008; Mould and Joel 2010). These methods avoid the structural determinism that results from transforming firm location data into a city network. But, perhaps even more significantly, direct analysis of the two-mode data does not cause the firms to disappear behind the scenes of a city network. Rather, it keeps both the cities and the firms in the foreground, thereby more closely paralleling the theoretical motivation of Taylor's (2001) interlocking specification (cf. Neal 2008).

A second possibility involves searching for alternative data that are more explicitly relational than the attribute data used by the interlocking approach. That is, the interlocking approach uses data for the attributes of individual cities (i.e., whether a firm operates an office within its borders) and derives data intended to capture intercity relationships. Some researchers have questioned whether such a transformation involves "turning apples into oranges," or creates new data from nothing (Nordlund 2004, p. 292). For example, the interlocking approach allows the 31,500 observations in the GAWC data set 11 firm location matrix (i.e., 315 cities × 100 firms) to yield 49,455 observations in a city network matrix (i.e., $[315^2–315]/2$)—a 57% increase in total observations achieved through mathematical transformation alone. Although lamenting the lack of genuinely relational data for cities has become common, rich sources of such data are available. Airline traffic data seem particularly promising because air travel remains a critical mode of transport for globally significant exchanges between cities (Smith and Timberlake 2001), and because methods have been developed to avoid the biases introduced by tourism and hub airports (Neal 2010).

As with all empirical inquiries, future research about the world city network is necessary. However, this article aims to provide a cautionary clarification about one of the dominant methodologies used to measure world city networks. Advancing our understanding of world city networks will require methods that do not make a priori assumptions about, or artificially constrain, the structure of the networks that we are seeking to measure. The interlocking approach to measuring the world city network remains a potentially useful approach, subject to the recommendations offered in this article, whereas other emerging methods offer promising alternatives.

Notes

1 A comprehensive list or review of studies employing Taylor's (2001) interlocking world city network goes beyond the scope of any article-length discussion. However, a fairly comprehensive repository of such materials is maintained by the GaWC work group at http://www.lboro.ac.uk/gawc/publicat.html.

2 Taylor's (2001) initial argument follows Sassen (1991) by focusing on the role of advanced producer service firms but has since been extended to other types of organizations.

3 Higher thresholds are possible, but the selection of a particular threshold value introduces an additional form of structural determinism that goes beyond the scope of this discussion. Specifically, the selection of any particular threshold above zero is largely arbitrary but substantially affects the structure of a network (e.g., Derudder and Taylor 2005).

4 Of course, the firms could be arranged in a different order, and the matrix would still reproduce the network in Fig. 1B. Similarly, the matrix could include additional firms with no locations in any of the cities without affecting its ability to reproduce the network.

5 While cliques are usually thought of as groups of three or more members, dyads are also cliques. Although no large groups or clusters of cities exist, Fig. 1B nonetheless contains four cliques, generated by the four firms. Similarly, Fig. 1C contains three cliques, generated by three firms.

6 When valued firm location data are used, an additional methodological challenge arises that goes beyond the scope of this discussion. Specifically, although mere firm presence in a city is easy to assess, the assignment of a specific service value is somewhat subjective. Taylor, Catalano, and Walker (2002, p. 2371) argue that any errors "are likely to be ironed out in the aggregate analysis" but offer no supporting evidence for this claim.

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