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Application of the Inter-locking Network Model to Mega-City Regions:

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Abstract

The interlocking network model, devised to study worldwide inter-city relations, is adapted to measure relations between cities within and beyond polycentric urban regions. The network makers are advanced producer service firms and their office networks are used to estimate positions of cities in networks. Data are collected covering nearly 2000 office networks across 200 cities in 8 mega-city regions. From these data, four estimates of the connectivities of cities (within their city-regions, nationally, at the European scale, and globally) enable unique comparisons of polycentricity at different geographical scales. The results are discussed for their policy implications.

Application du modèle de maillage aux mégalopoles: Mesure de la polycentricité dans les villes-régions et au-delà

P. J. Taylor, D.M. Evans et K.Pain

Résumé

Le modèle de maillage, conçu pour étudier les relations entre villes dans le monde, est adapté pour mesurer les relations entre villes de régions urbaines polycentriques et au-delà. Les concepteurs de ce réseau sont des entreprises de services de pointe et leurs réseaux de bureaux servent à estimer les positions des villes dans ces réseaux. Les données recueillies couvrent près de 2000 réseaux de bureaux dans 200 villes appartenant à huit mégalopoles. A partir de ces données, quatre estimations de la connectivité de ces villes (dans les villes régions, sur le plan national, à l'échelle européenne et mondiale) permettent des comparaisons uniques de la polycentricité à différentes échelles géographiques. Les auteurs examinent les résultats en ce qui concerne leurs implications politiques.

JEL: R, R5, R58
Mots-clés : régions multinodales, connectivité.

Anwendung des ineinandergreifenden Netzwerkmodells auf Megastadtregionen: Messung von Polyzentrizität innerhalb und außerhalb von Stadtregionen

P. J. Taylor, D.M. Evans and K.Pain

Abstract

Das ineinandergreifende Netzwerkmodell, das zur Untersuchung weltweiter Beziehungen zwischen Städten entwickelt wurde, wird zur Messung der Beziehungen zwischen Städten innerhalb und außerhalb polyzentrischer Stadtregionen angepasst. Die Entwickler der Netzwerke sind Wirtschaftsdienstleister; anhand der Filialnetze dieser Firmen werden die Positionen von Städten in Netzwerken geschätzt. Erfasst werden die Daten von beinahe 2000 Filialnetzen in 200 Städten innerhalb von 8 Megastadtregionen. Anhand dieser Daten werden mit Hilfe von vier Schätzungen der Konnektivität von Städten (innerhalb ihrer Stadtregionen, auf nationaler Ebene, auf europäischer Ebene und weltweit) eindeutige Vergleiche der Polyzentrizität auf verschiedenen geografischen Maßstäben möglich. Die Bedeutung dieser Ergebnisse für die Politik wird erörtert.

JEL: R, R5, R58
Keywords:
Multinoduläre Regionen
Konnektivität

Aplicación del modelo de redes entrelazadas para las regiones de mega-ciudades: medición de la policentralidad dentro y más allá de las ciudades región

P. J. Taylor, D.M. Evans and K.Pain

Abstract

El modelo de redes entrelazadas, creado para estudiar las relaciones interurbanas en todo el mundo, se ha adaptado para medir las relaciones entre las ciudades dentro y más allá de las regiones policéntricas urbanas. Los responsables de las redes son empresas de servicios avanzados de productores y sus redes de oficinas se utilizan para calcular las posiciones de las ciudades en las redes. Para este estudio se recabaron los datos de casi 2000 redes de oficinas en 200 ciudades en 8 regiones de mega-ciudades. A partir de estos datos, cuatro cálculos de las conectividades de las ciudades (dentro de sus regiones-ciudades, a nivel nacional, a escala europea, y globalmente) permiten hacer comparaciones exclusivas de la policentralidad a diferentes escalas geográficas. Asimismo analizamos los resultados para conocer sus repercusiones políticas.

Keywords:
Regiones multinodales
Conectividad

JEL: R, R5, R58

Introduction: third extension of the scope of a model

The interlocking network model of inter-city relations was devised to describe the way in which global/world cities are connected to one another in contemporary globalization (Taylor 2001). Eschewing Friedmann's (1986, 1995) 'world city hierarchy' and taking its cue from Sassen's (1991) 'global city' as a centre for advanced producer services, GaWC research has posited a process of world city network formation with 'global service firms' as the key agents or network makers. Quite literally, firms are modelled in the role of 'inter-locking' cities through their global office location practices. This model was then applied to 315 cities worldwide and a 'world city network' derived including measures of network connectivity between cities (Taylor 2002, 2004). The model has subsequently been interpreted as a generic process of inter-city relations (Taylor 2004). This argument has included both historical identification of inter-locking networks (Taylor 2007) and contemporary studies extending the range of interlocking agents beyond service firms (Taylor 2005a and b). In the POLYNET project (Hall and Pain 2006) the scope of the model has been extended a third time to describe inter-city relations *within* Mega-City Regions (MCRs) and beyond.

The extension of the inter-locking model to the POLYNET research was relatively simple in practice. Application of the model required information on where and how professional service firms use cities through their office networks. A potential pitfall in the model's extension related to reduction to city-region scale. The model requires there to be enough multi-locational firms to provide sufficient data for analysis. In the event numerous single city firms were found, which by definition could not 'inter-lock' cities, but there were ample other firms with offices in several cities to make analysis feasible; this paper describes the application and reports on the basic results.

The POLYNET project explored the notion that due to increasing integration in the advanced world service economy, facilitated by developments in information and communication technology (ICT), city-regions in North West Europe are becoming *functionally* multi-nodal. Thus it was posited that even the traditional city-region centred on a single central city is being replaced by the more complex urban order of polycentricity. Eight city-regions were chosen for study: South East England, the Randstad, Central Belgium, RhineRuhr, Rhine-Main, Northern Switzerland, Paris Region, and Greater Dublin. It was, of course, understood from the outset that these city-regions were diverse in urban structure with some having a tradition of polycentricity while others were historically monocentric or 'primate' in their urban pattern with one city dominating its hinterland in terms of its size and urban functions. The question was, therefore, whether polycentricity was becoming the norm across MCRs in the early twenty first century. As it turned out this was not an easy question to answer in any absolute sense.

The contributions of the interlocking network model to unraveling the complexities of polycentricity were fourfold.

1. The inter-city relations within MCRs are described to show how the city-

regions are integrated. This provides a first glimpse of comparative polycentricity.

2. The relative importance of cities within their regions in terms of their *intra-regional* network connectivities is computed to rank cities in each city-region. This provides material for initial measures of degree of polycentricity in city-regions so the latter are arrayed on a polycentric-primate sequence.
3. The relative importance of cities within their regions in terms of their *global* network connectivities is computed to again rank cities in each city-region. This provides an insight into 'outside business' use of cities in each region to produce alternative measures of degree of polycentricity in city-regions. This 'outside' view creates a different sequence of city-regions along the polycentric-primate array.
4. Thus, polycentricity is sensitive to the geographical scale of the operations being studied: this is measured and compared across four scales: regional, national, European and global. This is the particular complexity in understanding polycentricity that the interlocking network model highlights.

These four contributions are derived from a modeling exercise that encompasses assumptions than enable 'flow patterns' to be generated from attribute (i.e. static) data. This must be understood before the results are discussed: the first section of the paper reprises the model. The operation of the model is explained through a simple hypothetical example, for the underlying algebra readers are referred to previously published expositions (Taylor 2001, 2004). The second and third sections describe the data collection and the operationalization of the model. This was the largest data collection exercise of its kind ever undertaken. The next four sections present the results that make the contributions to understanding polycentricity described above. The findings are quantitative comparisons both within and across North West European MCRs. A brief conclusion relates the four contributions to other outcomes of the POLYNET project.

The interlocking network model

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The inter-locking network model identifies agents who use cities as nodes in their everyday business practices. The network makers we are interested in here are advanced producer service (APS) firms. For instance, a law firm may use partners and junior lawyers in several offices to draw up a particularly complex contract for a major client. Such use of a geographical spread of professional expertise is quite common in advanced financial, professional and creative services for major business clients. Thus providers of such services invariably have large office networks within and between cities. Such services are quintessentially city-based economic activities: therefore one important way in which cities and MCRs are integrated is through advanced service provision by firms that are simultaneously regional and extra-regional in their provision of services.

The inter-locking network models provides an initial means of overcoming one of the most frustrating problems for understanding how businesses use cities and MCRs: the chronic lack of inter–city data on knowledge-based flows. In the production of advanced services for business we know that there are numerous communications – face-to-face, telephone, fax and email – but there is no readily available information on these practices. Collecting such information is costly, time-consuming, and rarely very comprehensive. The inter-locking network model provides a simple surrogate measure using information that is readily available: we can easily find out where offices of service firms are located (e.g. from their websites) and, in addition, the functions and importance of different offices can often be gleaned from the available information. With a little simple modeling based upon plausible assumptions, such information allows us to estimate links between cities and the importance of a city in terms of its total links, which we term its 'network connectivity'.

The formulae for deriving surrogate measures of flow from firms' office networks are detailed in Taylor (2001). The basic premise is that the intra-firm flows of information, directions, knowledge, plans, advice, etc. between cities will be proportional to the importance of offices located in cities. That is to say, flows between two cities with large and important offices of a firm will be greater than flows between two cities with just minor offices in the firm's network. Such an assumption makes sense for advanced producer services in contemporary globalization (Sassen 2001): whereas earlier expansion of production firms was multi-national (originally to overcome protectionism) so that intra-firm flows were relatively small, with contemporary transnational processes, especially in services, intra-firm firm flows are central to large-scale (professional, creative and finanancial) projects. Thus the degree of difference in estimated flows can be computed from the potential number of intra-firm links between pairs of cities. This can be illustrated through a simple hypothetical example.

The office networks of three law firms that do business in a given MCR are shown in Table 1(a). Between them they have offices in four cities, three within the region and one beyond. For this advanced producer service, the importance of an office is given by the number of partners located in a city's office (partners are the cost centres of law practices). On the basic assumption that each partner generates approximately the same amount of business, we can sum the rows for each city to estimate the amount of law business done in each city. We call this measure a city's 'nodal size' in Table 1(b) and we can see that City X is the leading 'law city' in this example, with Cities Y and Z ranked second equal. Note that we do not include the extra-regional city in Table 1(b). This is because the firms are only from the MCR and therefore are used only to measure cities in that region. Obviously the extra-regional city will likely have other law firms from within its own region so that the limited data used here will under-estimate the law business in that city.

Nodal size is a simple initial measure of a city's importance as a service centre but does not fully use all the information contained in the data. Although the law firms in Table 1 (a) are similar in size – Law Firm A has 7 partners, and Law

Firms B and C have 5 partners each – the distributions of partners across the four cities are very different. And it is the latter that informs inter-city relations. This can be illustrated through diagrams derived from Table I (a). Figure 1 shows all *potential* intra-firm links between partners. For instance, for Law Firm A, City X has three partners, each of which can have contact with just the one partner in City Z: there are just three X-Z links. However, because there are two partners in City Y, there are six potential contacts to City X: there are six X-Y links. Also, because this law firm has an office in the extra-regional city, there are also potential contacts with Cities X, Y, and Z outside the region. In fact Law Firm A is the most comprehensive in its distribution of offices and therefore in potential contacts. As clearly shown in Figure 1, Law Firm B is purely regional in office distribution whereas Law Firm C has just one regional office so that all its inter-city contacts are outside the region. It is these stark contrasts between firms that are omitted from the simple nodal sums in Table 1 (b).

Network connectivity measures take into account different distributions of inter-city contacts. They can be computed as the sum of links a city has with other cities. In our simple example these can be counted from the intra-firm figures. Consider the links between Cities X and Y. There are 6 contacts through Firm A, two through Firm B and none through Firm C. Thus the total X-Y connection is 8 contacts. Similar exercises show that there are 7 contacts between cities X and Z, and 4 contacts between cities Y and Z. These are shown in Figure 2 (i). Such intra-regional links will be computed from large numbers of service firms in the POLYNET results described below. Here we will identify the largest inter-city link as the 'prime link' in each MCR. In this simple example the prime link is X-Y. Summing all the inter-city links for a given city provides the network connectivity measure for that city. It indicates how integrated the city is into the network, and is a far superior measure of the importance of a city than mere nodal size for the reasons previously enunciated. For City X on Figure 2 (i) this is simple 8 + 7 = 15; the network connectivities for cities Y and Z are 12 and 11 respectively. All three connectivities are listed in Table 1 (b) and can be compared to nodal size. Note that the results are different in terms of ranking – now City Y is ranked second above city Z despite both having the same nodal size. Looking at the data we can see that this is because City Y has the larger office for the largest Law Firm (A), whereas City Z has its largest office for the smaller Law Firm B. Having a firm being part of a larger office network means City Y is more connected than City Z.

Thus far we have not considered extra-regional inter-city contacts and city connectivities; this is shown on Figure 2 (ii). Clearly most contacts outside the region (9) go through City X and therefore this city has by far the highest of the extra-regional network connectivities. The latter are shown on Table 1 (b). The table also shows connectivity measures converted into percentages of the highest network connectivity. For both network connectivity measures the latter is for City X so that it is recorded as 100% in each case. This procedure facilitates comparisons between analyses based upon different numbers of contacts (in the hypothetical example) and firms (when applied across MCRs later). In particular, we can use the *average percentage of the non-leading cities* to measure the polycentricity of the city network. These are shown on Table 1 (b) and can be interpreted as follows. In the case of complete polycentricity all cities would have the same network connectivity thus the average for the cities deemed non-leading is 100%. In contrast in complete primacy all network connectivity is in the leading city (no polycentricity) so that the average for other cities is 0%. In the real world percentages will fall between 0 and 100 on this polycentricity scale. In Table 1 (b) polycentricity is much higher for connections within the region (76.5%) than for external connectivity (16.5%). In other words, City X is less dominant in connectivity within the region than it is outside the region. In fact this is a feature we find in the analysis of real data below: the leading city in a region is more dominant among other regional cities through outside links compared to internal links. However, in the analyses below we divide 'external cities' into three categories by geographical scale: cities within the country, leading European cities, and leading world cities. This we can measure extra-regional connectivities rather more subtly than in the hypothetical example we have just discussed.

All the results reported in this paper involve inter-city connections of pairs of cities and the network connectivities of cities. The only practical difference from the hypothetical example is that we use many more firms and cities. It is particularly important to use large numbers of firms so that the idiosyncrasies of individual firms are ironed out in the aggregate results to provide stable, replicable, estimates of inter-city linkages and city connectivities. This is the practical premise of the methodology: to operationalize the model large amounts of information about intra-firm connectivities are required. Only in this way can we provide robust evidence of the potential inter-city network connectivities that are conferred on cities by the office networks of firms.

Collecting the data: I Selecting firms and cities

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Data was collected on the offices of 1963 different service firms across 200 cities producing matrices including hundreds of thousands of pieces of information.[i] Eight service sectors were selected for study: accountancy, advertising, banking/finance, design consultancy, insurance, law, logistic services and management consultancy/IT. Data were collected for the nearly 2000 office networks within and beyond the eight MCRs by eight different city-region research teams. Details of this exercise can be found in Taylor et al (2006), only an outline is provided here. The *modus operadi* was to harness the local knowledge of each team: this meant that they were given autonomy in selection of local cities (and therefore MCR definition), national cities, and service firms (within the eight sectors). Thus differences in data mixes were built into the research design to reflect known variations in city economies and scales.

Using a variety of sources, each regional team created a universe of firms within their MCR and then selected firms from their universe for inclusion in the analysis. Firms were chosen both on the basis of local knowledge and for pragmatic reasons. First, firms had to be multi-locational, in the sense of having offices in at least two cities. Firms were also chosen on the basis of the quality of information available about them, and ease of obtaining it (e.g. whether a firm had an informative website). Overall the choice of firms had to correspond roughly to the relative importance of different sectors in that particular city region. Table 2 shows the different numbers of firms sampled by sectors and selected by each team. Each team carried out checks to ensure that variations in the sample shares broadly matched the structure of the sectors in each city region.

Table 3 shows the numbers of firms and cities studied in each MCR. Each regional team selected the urban centres that they thought were important to an understanding of the operation of their city region – it is these cities that are the focus of the research. Again this relied upon local knowledge. The full list of regional cities selected by each team is shown in the appendix. These cities were used to define city-regional servicing strategies by firms and the *regional inter-city links* and *connectivities for regional cities*. As previously noted the office networks of these selected firms within the region were also investigated to find further offices at national, European and global scales. At the national scale each team selected major national cities beyond their region that they thought were important for understanding their city region. The two German teams coordinated their national city selections to produce a common set. The Belgian team did not select a separate national set of cities because the Central Belgium city region included all major Belgian cities. The appendix also shows the national cities selected by each team. These cities were used to define national servicing strategies by firms and the *national connectivities for regional cities*.

At the European and global scales, the cities selected were necessarily the same for all teams. Based upon previous GaWC analyses of global connectivities (Taylor, 2004), 25 European top cities were identified: London, Paris, Dublin, Hamburg, Munich, Berlin Amsterdam, Düsseldorf, Frankfurt, Brussels, Zürich, as above (in the appendix), plus Stockholm, Prague, Barcelona, Moscow, Istanbul, Vienna, Warsaw, Lisbon, Copenhagen, Budapest, Milan, Madrid, Rome, and Athens. These cities were used to define European servicing strategies by firms and the *European connectivities for regional cities*. Global-level cities were similarly selected. Based upon previous GaWC analyses of global connectivities (Taylor, 2004), 25 top world cities were chosen: London, New York, Hong Kong, Paris, Tokyo, Singapore, Chicago, Milan, Los Angeles, Toronto, Madrid, Amsterdam, Sydney, Frankfurt, Brussels, Sao Paulo, San Francisco, Mexico City, Zürich, Taipei, Mumbai, Jakarta, Buenos Aires, Melbourne, Miami. These cities were used to define global servicing strategies and the *global connectivities for regional cities*.

Unsurprisingly, eight of the global level cities also appear in the European list. Likewise, some European cities will appear in national city lists, and some major national cities in regional city lists. Thus analyses at each different scale will not produce independent measures. This is not a problem because cities by their very nature are multi-scalar in their reach: London, Paris and other cities are simultaneously regional, national, European, and global service centres. However, it is useful that overlaps between scales generally involve less than one-third of cities in any list, allowing distinctive differences across scales to be measured.

Collecting the data: II Filling in the 'services activity matrices'

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These selected firms and cities set the dimensions of the services activity matrix that must be constructed. Because cities are related to four different geographical scales, the overall matrix can be divided into four service activity sub-matrices for the computation of connectivities at different scales. The matrices are filled by 'service values'; these are estimates of the importance of an office in a given city to the overall office network of a firm. The same rules for allocating service values were adopted across all scales.

To define service values, only two types of information were gathered: (i) indications of size of a presence in a city (e.g. number of practitioners or partners working in an office); and (ii) any indications that an office carries out extra-local functions for the firm (e.g. headquarters, research centre). Because the form of the information gathered is unique to each firm, it had to be converted into a common data matrix to make comparisons of service values across firms (and therefore all analyses) possible. The data collected consisted of estimates of the importance of each city or town to the office network of a given firm. The scale ranged from 3 indicating a city office with extra-locational functions to 0 for a city where the firm had no office at all. From these data four matrices arraying firms against cities at different scales were produced for each MCR. For instance, for the South East England region the four matrices arrayed the 143 firms as follows: at the city region scale the matrix was 143 firms x 9 cities (see Table 3); at the national scale an additional 6 cities were added (see the appendix) to produce a 143 x 15 matrix; at the European scale 24 cities (not 25 because London was already in the matrix from the regional level) were added for the regional scale) to produce a 143 x 41 matrix; and, at the global scale 24 cities were similarly added (again without double counting of London) to produce the final 143 x 60 matrix. Each of these matrices is the equivalent to the simple 3 law firms x 4 cities matrix of Table 1 (a), except they are very much larger! However the same principles apply for calculating inter-city links and city network connectivities although they can no longer all be shown as was the case in Figure 2.

Results: I Inter-city linkages within Mega-CityRegions

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The first findings are the *inter-city linkages* within the eight MCRs, equivalent to the links shown in Figure 2 (i). In each region, the pair of cities with the largest link is designated as the prime link of the region. For comparative purposes, this link is scored as 1.00 and the values of all other links are computed as proportions of the prime link. Table 4 presents a summary of the larger linkages.

The eight prime links are shown in the first column of Table 4 (a). Each involves the First City of each region and one other major city. First Cities are identified as the city in each region with the highest global connectivity, as measured in previous GaWC research (Taylor, 2004). It is particularly important to stress that the methodology used here analyses each region separately, so *it is not possible to say that one prime link is larger than any other* they are each simply the largest in their respective regions. But it is possible to look at relative patterns of links and their sizes within regions – and it is this that makes the analyses useful in understanding potential functional polycentricity.

The second column of Table 4 (a) shows the 11 other highest links to the First City of each MCR. This list has to be interpreted with care. Links to Paris are conspicuous, totalling four in all. What this shows is that in this MCR the prime link (Paris–Rouen) is not particularly dominant. This implies that Paris is at the centre of a region with a number of similar links, possibly indicating the primacy of Paris. South East England, Greater Dublin and Rhine-Main each have two major First City links, again implying that the prime link is not particularly dominant in their respective regions. Again, this might indicate primacy in these three regions. The other link in the table features Düsseldorf and it will be shown in the analysis below that in this case a rather different situation prevails.

Table 4 (b) shows the highest 15 links that do not include the First City. There is one remarkable feature of this list: the majority, nine, of the links are from just one MCR, RhineRuhr. This is undoubtedly an indication of the polycentricity of this region. Clearly in this region not all major links are to Düsseldorf: five other RhineRuhr cities feature here. The Randstad is the only other MCR to feature prominently in Table 4 (b) with three links other than to Amsterdam listed. Again this implies a degree of polycentricity. Of the other six MCRs, three (Central Belgium, Rhine-Main and South East England) have just one link each listed and three (Greater Dublin, Paris Region and EMR Northern Switzerland) are not represented at all. This further suggests primacy for the latter three and note also that the South East England link (Reading–Southampton) only qualifies for the list at the threshold level.

Polycentricity conclusion: from this evidence on inter-city linkages, three statements appear to be reasonable summaries:

1. Paris Region, Rhine-Main, Greater Dublin and perhaps South East England appear to be relatively primate MCRs.
2. RhineRuhr appears the most polycentric MCR, and the Randstad region also appears to be polycentric.
3. It is not clear whether the Central Belgium and Northern Switzerland are primate or polycentric.

Results: II City connectivities within Mega-CityRegions

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The findings reported in this section are the *city network connectivities*, showing how well cities are integrated into each MCR (as in the regional connectivity percentages column of Table 1 (b)) – in other words, their integration through business networks that are regional in scope. The results for top six cities in each of the eight MCRs are shown in Table 5. The percentages in this table can be interpreted as follows. Taking the first case as the example, it is clear that in the Randstad MCR, Amsterdam and Rotterdam are by far the most connected cities: very many service firms do important business in both cities thereby connecting them to the rest of the region. Utrecht and The Hague are quite well connected, whereas the network connectivities of Alkmaar and Amersfoort are relatively low. Thus, a clear pattern of network connectivities is shown for the Randstad, dividing the cities into three pairs.

A simple inspection of Table 5 shows that there are four city-regions were the second city is a close challenger to the first city in terms of connectivity: Cologne is almost the equal of Düssdeldorf, and Rotterdam, Antwerp and Basle are near rivals to Amsterdam, Brussels and Zürich respectively. But these 'duopolies' of connectivity dominance only tell part of the story. Also included in Table 5 are the average percentages for the 5 non-leading cities in each region which constitutes our polycentricity scale as described previously (Table 1 (b)). The four MCRs just mentioned now feature as the regions with polycentricity 50% and above but the differences are quite large. RhineRuhr with 87% is far more polycentric than any other region: the Randstad is a distant second on 63%. Central Belgium and Northern Switzerland with percentages in the fifties appear to be the largely 'duopoly regions'. The other four MCRs have polycentricity scores in the forties suggesting that London, Paris, Frankfurt, and Dublin are not as 'primate' as commonly viewed, at least at the regional scale.

Polycentricity conclusion: these results allow us to rank North West European MCRs in terms of their polycentricity with regard to *regional scope* business networks: 1. RhineRuhr; 2. the Randstad; 3. Central Belgium; 4. Northern Switzerland; 5. Paris Region; 6. Greater Dublin; 7. Rhine Main; 8. South East England.

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Results: III Global connectivities of cities in Mega-City Regions

As well as coding the service firms offices within the MCRs, we also searched out their offices in the 25 leading world cities and estimated the importance of these cities to the firms' business. These data allow us to calculate new network connectivities for the cities and towns of North West European MCRs within the wider global economy via leading world cities. The results are shown in Table 6. Looking again at the first MCR in the table, we can interpret these results as follows. Amsterdam is clearly more connected worldwide in terms of services than is Rotterdam – the service firms in Amsterdam have office networks that do more business in, and therefore have more links to, major cities across the world economy. In this case, Utrecht and The Hague have relatively low service links to the world economy, and the final two cities, in this table Amstelveen and Haarlemmermeer, have even fewer connections. Clearly, for global service connections it is Amsterdam that is the 'gateway' for the Dutch MCR.

The major interest in Table 6 is its contrast with Table 5. It is not the minor changes of towns with low connectivities that is important, rather it is the consistent pattern of a lessening of polycentricity for global connections: in other words, increasing primacy. In every one of the eight regions, the city ranked first for intra-regional connections (Table 5) increases its dominance markedly over the second ranked city in Table 6. Thus Cologne declines from 99 per cent of Düsseldorf's regional scale connectivity to only 58 per cent of its global connectivity: when it comes to global servicing, it is Düsseldorf that is outstandingly the main city in RhineRuhr. Rotterdam is the 'second city' that maintains most connectivity in terms of global links while, in the other direction, primacy is most enhanced with global links for Dublin: other cities in this MCR are effectively unconnected directly by services to rest of the world-economy.

Polycentricity conclusion: Clearly these results show that service network connectivities vary with the geographical scale of services, with global services exhibiting a concentration of provision in just one citiy of each MCR. In other words, from the outside (the perspective of global business) the MCRs appear much less polycentric than their internal regional scale integration previously suggested.

Results: IV Measuring Polycentricity across Geographical Scales

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These scale variations can be further analysed by measuring polycentricity also at the national and European scales. The resulting four-scale comparisons are shown in Table 7 alongside regional and global scale polycentricities from Tables 5 and 6 respectively. The table can be read row by row to show the polycentricity-scale relationships. Variation of polycentricity is confirmed and it is shown that it tends to decline as geographical scale increases, as the previous regional-global comparisons suggested. But the gradients are not all smooth: there are two examples of 'reverse pairings': the polycentricity of the Randstad increases slightly between regional and national scales, as does Paris Region between European and global scales. However there is one important consistency across all MCRs and this is the large drop in polycentricity between national and European scales. What this suggests is that the services we are studying operate to produce two distinctive scales of business, regional/national and European/global. In other words, multi-locational firms that are regional are also national; if they extend their office networks into Europe they will also be global in scope.

We can take this 'two-scale' finding into reading Table 7 by columns, comparing the rankings of MCRs. The regions are ordered in the table from largest to lowest polycentricity at the regional scale. In the previous discussion at this scale the MCRs were treated as two groups separated by the 50% polycentricity line. Above the line this grouping stays together as they each broadly have a similar decline in polycentricity with scale. However, note that at the global scale the Randstad has 'caught up' with RhineRuhr in polycentricity. It is below the 50% marker that very different patterns emerge. For two regions, Rhine-Main and Greater Dublin, there is a rapid decline in polycentricity so that, at the European and global scales, polycentricity has all but disappeared. This means that in these regions Frankfurt and Dublin are very primate with respect to European/global business and effectively constitute sole ‘gateways’ into their respective regions. This contrasts hugely with the other two lower ranked regions from the regional analysis, Paris Region and South East England. The big change comes at European and global scales where Paris Region and South East England are now ranked third and fourth in polycentricity behind only RhineRuhr and the Randstad. This suggests that regional cities other than Paris and London are relatively well connected into the wider world economy. This means that whereas Frankfurt and Dublin retain a traditional form of primacy at the larger scales, Paris and London, traditionally the archetypal primate cities, are located in much more functionally polycentric regions. It is clear from Table 7 that the latter regions are much more like the recognised multi-nodal urban orders of RhineRuhr and the Randstad than they are to Rhine-Main and Greater Dublin when it comes to contemporary globalization processes. With the information at our disposal we can only speculate as to how this relatively surprising result has come about. It is surely not a coincidence that the result features London and Paris which are the largest world cities with the greatest service functions in Europe. Thus it might be that this size factor generates more service dispersal opportunities producing more connected outer cities around London and Paris than around Dublin and Frankfurt.

One final point on these polycentricity-scale comparisons needs to be made. The decline in polycentricity is very real: note that the highest scores for European and global scales in Table 7 are below 40 whereas the lowest scores for the regional scale are above 40. In other words polycentricity defined by regional links is always higher than polycentricity defined by global links, whatever the region.

Polycentricity conclusion: Beyond the detailed empirical findings, the scale analysis has emphasized the complexity and scale-dependency of the polycentricity concept. Different scales of business servicing produce quite different results suggesting we should eschew from referring to polycentricity as a simple singular property of a city-region.

Conclusion

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This new application of the interlocking network model has produced four contributions that enhance our understanding of the polycentricity of North West European MCRs. The specific empirics are intriguing and the overall results thought provoking, especially the revealed complexity of our subject matter. But this quantitative research can only take our understanding so far. We are dealing with on-going processes that can only be fully explored through other methodologies that deal directly with the agents doing the networking.

An extensive research programme such as the one reported above provides researchers and policy-makers with two important related outcomes. It provides a quantitative and descriptive back-cloth to what is being investigated. In this case we have provided some detailed descriptions of the inter-urban functional linkages of MCRs in North West Europe that result from their connectivity to knowledge-based business networks at regional to global geographical scales. The analysis thus goes beyond understandings of city-region change that are based on 'state-istics', as in conventional regional studies. It also provides guidance to further enquiry – what to explore with the network makers. In this case, numerous interesting findings demand further attention.

First, in order to facilitate polycentricity comparisons between the MCRs, as explained, differences in the global connectivity of their First Cities was discounted. The linkages between pairs of cities in each MCR were simply calculated as a proportion of the connectivity between First and second cities in each case. Taking into account the finding that connectivity to global networks produces a very different perspective on MCR polycentricity, a key area for further study will be to discover the difference the degree of First City global connectivity makes to the relative strength of MCR functional polycentricity.

Second, the finding that office networks that are regional are also national in scope, has potential significance for inter-regional urban linkages and Member State interests in promoting more balanced and competitive national knowledge-based economic development – a crucial policy scale in the recent EU Community Lisbon Programme (EUROPEAN COMMISSION, 2005). It is now possible to extend the POLYNET quantitative analysis to discover potential inter-urban linkages between the MCRs and other national cities and regions, the degree of national functional polycentricity and the importance of MCR First City global connectivity to this.

Third, the finding that office networks that are European are also global in scope, has potential significance for inter-regional urban linkages and European Union (EU) interests in promoting more balanced European knowledge-based economic development – the ongoing key priority of the Lisbon Strategy and fundamental European priorities to promote territorial cohesion (EUROPEAN COMMISSION 2000). It is now possible to extend the POLYNET quantitative analysis to discover potential inter-urban linkages between the eight MCRs and other cities and regions beyond the seven Member States involved in the present study including less economically developed regions beyond North West Europe. The analysis would inform the question of Europe-wide functional polycentricity and the importance of MCR and First City global connectivity to this.

Fourth, there is a need to add a dynamic element to the cross-sectional results presented. Globally, it has been shown that inter-city network relations are relatively stable over the short term (Taylor and Aranya 2007) and it is important to see the degree to which this is true for relations within mega-city regions. For instance, are on-going globalization processes enhancing the primacy in the MCRs as the leading cities become 'global gateways' to their regions? Other related work suggests outcomes are more complex than just enhancing gateways (Rossi and Taylor2006) but we need to know how such complexities pan out within MCRs.

These opportunities for further study would also take the consideration of polycentricity in the European Spatial Development Perspective (ESDP) (EUROPEAN COUNCIL 1999) forward in two important ways. Firstly, the results would inform the question of scale: transboundary geographies of uneven functional development that are impossible to assess using conventional statistical analysis. Secondly the results would inform the question of knowledge-based functional, as opposed to simple morphological, polycentricity – again, this cannot be achieved using official statistics that do not distinguish between knowledge-intensive, networked services and other retail and local markets oriented services. It is clear from the findings that assessments of polycentricity that are based on rigid regional boundaries and that do not take into account economic interactions that link cities across these do not provide a sound basis for spatial and economic policy.

Finally, it has been demonstrated in POLYNET that quantitatively derived mapping of inter-urban and inter-regional advanced service network linkages can provide vital clues as to the firms and locations where further detailed investigation through in-depth interviews needs to be directed. As the articles that follow demonstrate, together, quantitative and qualitative analysis can be important pointers for policy by revealing multi-scale relations between the MCR places and the knowledge economy. Potentially, further research can extend these insights to wider policy scales in early twenty first century Europe.

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Table 1 The office networks of three law firms

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(a) Basic data

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	Number of partners:		
	Law firm A	Law firm B	Law firm C
Regional City X	3	2	2
Regional City Y	2	1	0
Regional City Z	1	2	0
Extra-regional City	1	0	3

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(b) Network nodes and connectivities

	Nodal size	Regional network connectivity		Extra-regional network connectivity	
		Total links	% of highest	Total links	% of highest
Regional City X	7	15	100	9	100
Regional City Y	3	12	80	2	22
Regional City Z	3	11	73	1	11
Average % of non-leading cities			76.5		16.5

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Table 2 Distribution of Firms Studied in Mega City Regions by Sector

Mega-City-Region	Accou nt-ancy	Adver t-ising	Bankin g/ Finance	Desig n Consu lt-ancy	Insur-ance	La w	Logis-tical Servic es	Manag e-ment Consult -ancy
South East England	20	20	20	25	8	16	11	23
Randstad	23	20	22	23	17	23	18	30
Central Belgium	26	38	35	30	18	34	47	96
RhineRuhr	21	27	73	18	27	21	19	91
Rhine-Main	26	56	148	47	55	28	22	76
ENMS Northern Switzerland	10	25	15	17	11	10	31	16
Paris	55	27	24	22	24	26	32	37

Region								
Dublin	23	18	21	22	23	34	22	20

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Table 3 Data Production: Service Firms And Cities/Towns across the Mega-City Regions

Mega-city region	Number of service firms	Number of cities/towns
The Randstad	176	12
Central Belgium	324	5
Greater Dublin	183	8
Rhine-Main	458	5
South East England	143	8
Paris Region	247	18
RhineRuhr	297	8
Northern Switzerland	135	7

Table 4 Major intra-regional linkages

(a) Major linkages to the First City

Prime links [All 1.00]	Other First City links ≥ 0.60	
Amsterdam – Rotterdam	London – Reading	0.93
Brussels – Antwerp	Frankfurt – Mainz	0.91
Dublin – Naas-Newbridge	Paris – Reims	0.80
Düsseldorf – Cologne	Paris – Amiens	0.79
Frankfurt – Wiesbaden	Paris – OrlÈans	0.79
London – Southampton	Dublin – Dundalk	0.77
Paris – Rouen	Düsseldorf – Dortmund	0.75
Zürich – Basle	London – Cambridge	0.70
	Frankfurt – Darmstadt	0.65
	Dublin – Drogheda	0.64
	Paris – Chartres	0.62

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(b) Major linkages that by-pass the First City

Links not including First Cities (≥ 0.40)	
Cologne – Essen	0.76
Cologne – Dortmund	0.73
Antwerp – Ghent	0.59
Bonn – Cologne	0.58
Dortmund – Essen	0.57
Mainz – Wiesbaden	0.51
Rotterdam – The Hague	0.48
Rotterdam – Utrecht	0.47
Duisburg – Essen	0.47
Bonn – Dortmund	0.45
Bonn – Essen	0.45
Dortmund – Duisburg	0.44
Cologne – Duisburg	0.44
The Hague – Utrecht	0.42
Reading – Southampton	0.40

Table 5 City Network Connectivities and Polycentricity at the regional scale

City/town	%	City/town	%	City/town	%
The Randstad		*Rhine-Main*		*RhineRuhr*	
Amsterdam	100	Frankfurt	100	Düsseldorf	100
Rotterdam	91	Wiesbaden	61	Cologne	99
Utrecht	72	Mainz	57	Dortmund	90
The Hague	71	Darmstadt	44	Essen	89
Alkmaar	40	Aschaffenburg	27	Bonn	79
Amersfoort	39	Hanau	25	Duisburg	77
Polycentricity	63	Polycentricity	43	Polycentricity	87
Central Belgium		*S E England*		*Northern Switrld*	
Brussels	100	London	100	Zürich	100
Antwerp	94	Reading	52	Basel	80
Ghent	66	Southampton	47	St Gallen	53
Hasselt-Genk	48	Cambridge	39	Zug	49
LiËge	48	Milton Keynes	34	Lucerne	36
Mechelen	25	Crawley-Gatwick	33	Aarau	33
Polycentricity	56	Polycentricity	41	Polycentricity	50

Greater Dublin		*Paris Region*			
Dublin	100	Paris	100		
Naas Newbridge	61	Rouen	61		
Dundalk	53	OrlÈans	53		
Drogheda	43	Reims	45		
Navan	31	Amiens	41		
Bray	31	Chartres	36		
Polycentricity	44	Polycentricity	47		

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Note: Polycentricity is measured by the average % of the 5 non-leading cities, see Table 1 (b).

Table 6 City Network Connectivities and Polycentricity at the global scale

City	%	City	%	City	%
The Randstad		*Rhine-Main*		*RhineRuhr*	
Amsterdam	100	Frankfurt	100	Düsseldorf	100
Rotterdam	68	Wiesbaden	12	Cologne	58
Utrecht	37	Mainz	8	Essen	39
The Hague	36	Darmstadt	7	Dortmund	34
Amstelveen	23	Aschaffenburg	3	Bonn	26
Haarlemmerm'r	18	Hanau	3	Duisburg	22
Polycentricity	36	Polycentricity	6	Polycentricity	36
Central Belgium		*S E England*		*N Switzerland*	
Brussels	100	London	100	Zürich	100
Antwerp	38	Reading	24	Basel	41
Ghent	20	Cambridge	17	Zug	13
Hasselt-Genk	14	St Albans	15	St Gallen	11
LiËge	13	Southampton	11	Aarau	10
Mechelen	9	Crawley-Gatwick	11	Lucerne	8
Polycentricity	19	Polycentricity	24	Polycentricity	17

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Greater Dublin		*Paris Region*			
Dublin	100	Paris	100		
Naas Newbridge	3	Rouen	37		
Dundalk	3	OrlÈans	32		
Drogheda	2	Reims	25		
Navan	2	Marne-la-VallÈe	20		
Bray	1	Amiens	19		
Polycentricity	2	Polycentricity	27		

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Note: Polycentricity is measured by the average % of the 5 non-leading cities, see Table 1 (b).

Table 7 Polycentricity for Different Geographical Scales by Mega City Region

MEGA CITY-REGION	Regional Scale %	National Scale %	European Scale %	Global Scale %
RhineRuhr	87	75	39	36
The Randstad	63	69	36	36
Central Belgium	56	56	20	19
Northern Switzerland	50	39	17	17
Paris Region	47	38	25	27
Greater Dublin	44	21	3	2
Rhine Main	43	15	7	6
South East England	41	41	27	24

Notes: (i) Polycentricity is measured by the average % of the 5 non-leading cities, see Table 1 (b); (ii) The Belgium national scale was conflated with the Brussels regional scale, see data collection.

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Appendix Cities chosen for study by mega-city region

MCR	Regional cities	National cities
South East England	London Cambridge Reading Milton Keynes St. Albans Southampton Crawley- Gatwick Swindon Bournemouth	Birmingham Manchester Sheffield Bristol Newcastle Nottingham
The Randstad	Amsterdam Rotterdam The Hague Utrecht Amersfoort Haarlemmermeer Amstelveen Alkmaar Almere	Eindhoven Groningen Tilburg Arnhem s-Hertogenbosch Breda Nijmegen Apeldoorn Zwolle

	Haarlem Hilversum Zaanstad	Maastricht Enschede Leeuwarden	
Central Belgium	Brussels Antwerp Gent LiËge Mechelen Hasselt-Genk	-	
RhineRuhr	Dortmund Essen Duisburg Düsseldorf Cologne Bonn *National – as for Frankfurt*	*Outer Region* Krefeld Mˆnchengladbach Remscheid Solingen Wuppertal Velbert Menden Viersen Wesel Dorsten	RhineRuhr
Rhine-Main	Frankfurt	Aachen	Rhine-Main

	Mainz Wiesbaden Darmstadt Aschaffenburg Hanau	Augsburg Berlin Bielefeld Bonn Bochum Braunschweig Bremen Chemnitz Cologne Dortmund Dresden Duisburg Düsseldorf Erfurt	
EMR Northern Switzerland	Aarau Baden-Brugg Basel Lucerne St Gallen Winterthur Zug	Bern Chur Geneva Lausanne Lugano	
Paris	Paris	Lyon	Paris Region

Region	Cergy-Pontoise Marne-la-VallÈe Saint-Quentin-en-Yvelines Evry/Melun-SÈnart Roissy Meaux Mantes-la-Jolie/Les Mureaux CompiËgne Beauvais Evreux Rouen Reims Amiens OrlÈans Chartres Le Mans Troyes	Lille Marseille Toulouse Bordeaux Strasbourg Nantes	
Greater Dublin	Dublin Balbriggan Bray	Limerick Shannon Cork Galway	

	Drogheda Dundalk Navan Maynooth Naas Newbridge Wicklow	Waterford Sligo Belfast Newry Derry

Source : Taylor et al (2006)

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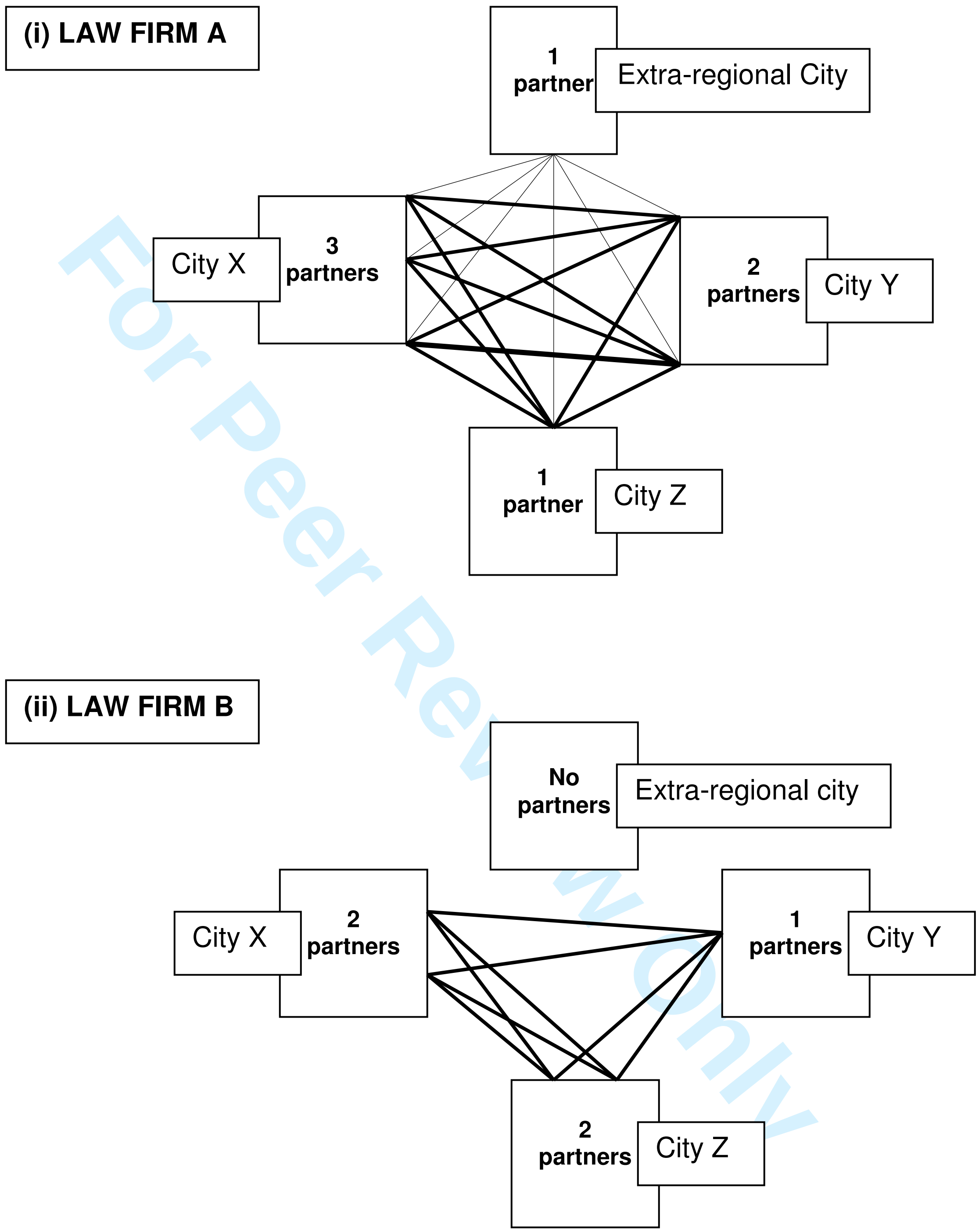
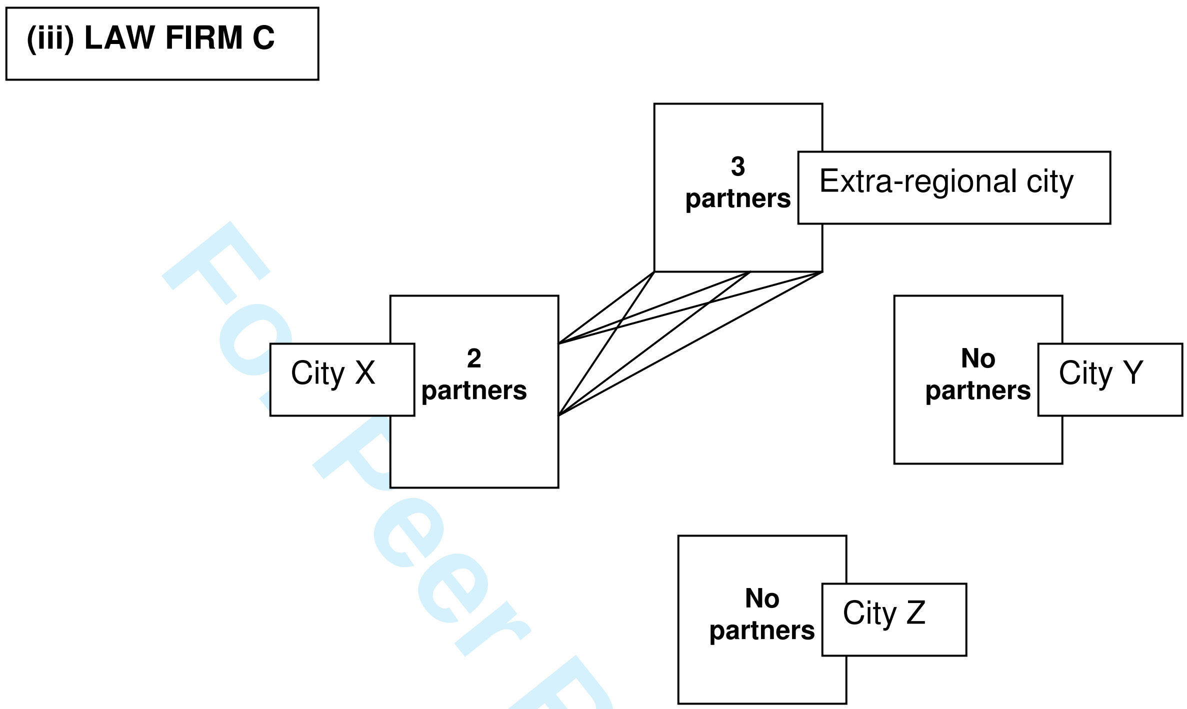
[i] The data was collected by eight different teams:
Paris: Ludovic Halbert with the help of Maude Sainteville and Renan Combreau
Belgium: Laurent Aujean, Etienne Castiau, Marcel Roelandts, Christian Vandermotten
Dublin: Chris van Egeraat, Martin Sokol, John Yarwood
North Switzerland: Lars Glanzmann, Nathalie Grillon, Christian Kruse, Alain Thierstein
Randstad: Bart Lambregts, Merijn van der Werff, Robert Kloosterman
Rhine-Main: Christian Fischer, Tim Freytag, Michael Hoyler, Christoph Mager
RhineRuhr: Wolfgang Knapp, Daniella Scherhag, Peter Schmitt
SE England: Kathy Pain, David Walker, David Evans
We acknowledge their essential contribution to this paper

Figure 1 **Intra-firm links**




(iii) LAW FIRM C
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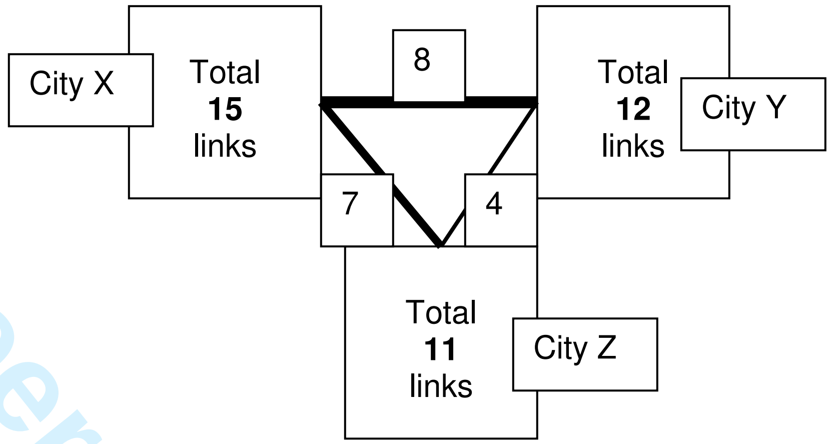
partners
Extra-regional city
City X
2
partners
No
partners
City Y
No
partners
City Z

Figure 2 **Inter-city links**

(i) INTRA-REGIONAL LINKS



(ii) EXTRA-REGIONAL LINKS