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Ranking functional urban regions: A comparison of interaction and node attribute data

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Although many studies employ either interaction- or node-attribute data to study the positions of cities in the urban system, relatively little is known about the relationships between these two different types of data. This study explores this relationship by ranking and comparing 39 metropolitan areas in Western Europe according to their relative role in the system of flows and their concentration of functions. The former is measured via the intensity of interaction, and the connectivity or distribution of interaction across links associated with nodes. The latter is measured via four dimensions: its sociodemographic, economic, transport accessibility, and tourism characteristics. The results show that the relationships between interaction and node attributes differ for types of flow. Compared with business flows, holiday flows and node-attributes are less strongly correlated. We also find that the differences between the two rankings can be explained to some extent by the fact that corporeal interaction is influenced by the physical barriers imposed by sea.

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Introduction

The positions of cities within an urban system have been studied on a variety of geographical scales ranging from the metropolitan and regional level (Van der Laan, 1998), to the national level (Chapple et al., 2004), the European level (Wall and Van der Knaap, 2005), and the global level (Taylor, 2004). Two main approaches of studying the positions of cities can be distinguished by the type of data used in the analysis. First, one can characterise cities' importance by using data on the attributes of nodes such as the population size, economic profiles, and the presence of transport and communication functions in cities (Taylor and Hoyler, 2000). Second, one could rank cities from an interaction

perspective by using flow data (Smith and Timberlake, 2001). This approach concentrates on the degree to which nodes interact with each other in the system of flows.

Although the fundamentals of both approaches are well documented, the nature of the relationship between these two approaches has remained hitherto largely unexplored. One might expect them to overlap considerably, because flows of people, goods, information, and money produce and are produced by the functions present within cities (Hohenberg and Lees, 1995). Many studies are based on the assumption that the two types of data are very strongly correlated (Derudder and Taylor, 2005; Taylor, 2001). This assumption may be questioned, however. Short (2004), for instance, argues that there are numerous city nodes one might expect to have an important role in the global network on the basis of their internal characteristics, but which do not in fact have such a role.

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Our study aims to examine the extent to which the positions of cities using the interaction- and node-attribute data correlate with each other, and how possible (dis)similarities between the two can be explained. The insights thereby obtained could provide a better basis for the data selection for studies on urban systems. These include studies of urban networks and spatial integration processes, which have received considerable attention in the European literature (NORDREGIO, 2004).

Although there are several types of flow that could be used for studying interaction, we have concentrated on flows of people travelling between distinct metropolitan areas for two reasons. First, face-to-face relationships continue to be important for the development of urban systems (Smith and Timberlake, 2001). Personal mobility over longer distances has increased in terms of both the frequency of trips and also of the distance travelled, despite the telecommunication revolution that may substitute for travel (Urry, 2003). Second, it is the less frequent journeys undertaken over greater spatial distances rather than daily (commuting) journeys that are pertinent to the development of urban systems on the higher spatial scale (Dieleman and Faludi, 1998). The analysis has been conducted separately for business and holiday journeys. Although the literature on urban systems concentrates mainly on economic relations (that is, linkages between and within firms located in different urban nodes (Taylor, 2004)), we argue that other mobility flows, such as holiday journeys, should also be examined. This is because in many countries non-work-related journeys account for the greater proportion of personal journeys, particularly over long distances (Dateline Consortium, 2002), and play an important part in influencing interactions between urban areas.

In the next section, we present a theoretical framework and review the factors that have been employed to rank urban areas in studies using interaction- and node-attribute data. Our data and methodology are then briefly described. Subsequently, we present and discuss the empirical results. The final section concludes the paper with recommendations for further research.

Theoretical framework

The classic literature on urban system analysis perceives an urban system as consisting of two main types of element: nodes and linkages between them (Simmons, 1978). These two types of element are highly interdependent; the attributes of nodes (both tangible attributes such as offices and amenities; and intangible attributes such as culture and identity (Wong, 1998)) and interaction (for example, flows of information, money, and people) mutually influence and determine one another (Simmons, 1978). This reciprocal process of the determination of the characteristics of nodes and flows is clearly described

by Janelle (1969). He asserts that the reduction in travelling costs resulting from technological innovations in transport has facilitated the *centralisation* of various activities in particular places and the *specialisation* of other places in specific activities at the expense of others. These spatial reconfigurations may lead to an *increased interaction* and trigger new demands for increased accessibility. Spatial deconcentration may occur when reduced accessibility is traded off for lower locational costs such as land rent and lower levels of congestion.

Four qualifications of this conceptual model of spatial reconfigurations seem appropriate. First, although Janelle's model is mainly applied to spatial developments at regional level, the conceptual relationships among accessibility, interaction, centralisation/specialisation, and locational costs are also applicable to reorganisation processes at higher spatial scales. Second, in the Information Age innovations in information and communication technologies can be important drivers of the reconfiguration processes described in addition to those in transport. Third, in Janelle's model the chain of cause and effect is unidirectional; centralisation and specialisation precede increased interaction. However, in reality an expansion of flows caused by, for example, changes in the migration of households or firms or commuting flows could also lead to the development and reconfiguration of activities. Lastly, the process model is highly mechanistic and deterministic. Innovations in technological systems are not the only drivers of spatial configurations. These processes are mediated by the main agents of change: business organisations, planning authorities, and households.

While it can be criticised, Janelle's model does make it clear that attributes of nodes and interactions are interrelated and that both should be considered to gain better understanding of urban systems. Previous studies have tended to examine the rankings of cities from either a node-attribute or an interaction perspective and have (implicitly) assumed that these two elements resemble one another. We have investigated whether this hypothesis is true and how possible similarities and deviations can be explained. The two approaches are discussed in more detail below.

The *node-attribute approach* focuses on the concentration of activities or functions in a node. A general assumption is that the most important nodes in the system have the largest concentration of such functions as products, facilities, and services. In the literature, at least three sets of node attributes to measure these functions can be identified. First, the *sociodemographic profile of a node* is often measured by the population size and the level of education of the inhabitants (Atzema and Lambooy, 1999; Hohenberg and Lees, 1995). Both of these are believed to correlate positively with the importance of a node in the system: large population size is a surrogate measure for a wide range of specialised products and services available in a node; the supply of highly-

educated labour is a precondition for the economic success of a node in advanced economies. Second, a *node's economic profile* has been measured in several ways, but GDP per capita is used most frequently, partly because of the ease of obtaining this data (Atzema and Lambooy, 1999). The percentage of employment in knowledge-intensive activities and scientific research is also used as a surrogate for the importance of a node in advanced economies (Chapple et al., 2004). Third, the importance of a node in terms of its *tourism profile* is determined on the basis of the number of facilities and factors determining the attractiveness of a node as a tourist destination: the number of hotels and cultural sites, the length of the seashore, and the climate (Enright and Newton, 2004 for example). These tourism attributes are similar to the concept of the 'consumer city' coined by Glaeser et al. (2001). They maintain that the role of the city as a consumption centre is becoming increasingly important, since urban amenities play a part in determining the economic and population growth of cities. Nevertheless, tourism is only one of many functions of the consumer city.

As explained above, the attributes of nodes and their interaction are highly related. In many cases, the use of the node-attribute approach tends to reflect the paucity of suitable interaction data (Short et al., 1996). To overcome data deficiency, some sophisticated methods have been applied to derive the interaction from the internal characteristics of nodes. Researchers affiliated to the Globalization and World Cities Centres and Network, for instance, have constructed relational data based on the number of major global service firms in a city (Derudder and Taylor, 2005; Taylor, 2001). Others use the capacity of transport networks or the *accessibility by transport mode* measuring the number of opportunities that can be reached within a certain time limit via motorway, high-speed rail, and airline networks to infer the interconnection between nodes (Bruinsma and Rietveld, 1993). Nodes with high levels of accessibility to other nodes are ranked at the top, because networks of transport services facilitate and strengthen their competitive position with respect to certain activities for which (international) interaction is essential.

However, the use of the node-attribute and the derived interaction data have both been criticised, because the extent to which the internal characteristics of nodes can be translated into the interaction is unclear (Taylor, 2004). What is present in a node can also have a purely local function, catering for the nodes' inhabitants, firms, and institutions, and need not be targeted towards other nodes of the system (Robinson, 2005). These considerations imply that the use of actual interaction data may, in some cases at least, be preferred.

The *interaction approach* focuses on actual interaction that links different nodes together, such as flows of people (Smith and Timberlake, 2001), capi-

tal (Meyer, 1986), and information (Mitchelson and Wheeler, 1994). This approach has been employed since the 1960s in the geographic literature (Nystuen and Dacey, 1961) and has become more widespread since, particularly in 'world cities' research (Taylor, 2004). The importance of a node from an interaction perspective is often measured in two ways: *the strength of interaction* and *the connectivity of a node*. Concerning the former, the more intensively a node interacts with others, the more dominant it becomes, because it illustrates the ability of activities in that node to control or dominate activities throughout the system (Alderson and Beckfield, 2004). With regard to the connectivity, a node is more dominant when it interacts with many nodes in the system (Alderson and Beckfield, 2004) and ideally the strength of interaction should be equally strong across all links associated with a given node. This is because this situation indicates the great extent of the power a node wields in controlling or dominating activities in multiple nodes in the system (Eberstein and Frisbie, 1982).

A review of previous studies suggests that the geographies of various types of flow are not the same. West European cities, for instance, are over-represented when the global service firms' network is concerned (Robinson, 2005), while the air passenger network reveals more diverse types of cities, because it does not differentiate between specific types of activity (Derudder et al., 2005). The difference in the geography of flows implies that it is important to consider different types of flow when studying the interaction between metropolitan areas.

As with the node-attribute approach, the interaction approach has also been criticised for giving a one-sided account by disregarding the functions that make up the actual economies of cities (Robinson, 2005). The drawbacks of node-attribute and interaction approaches suggest that both types of element should be considered to attain a better understanding of the positions of cities within an urban system. Furthermore, some work has been done to understand the relationships between interaction- and node-attributes (for example, Taaffe, 1956; Taylor et al., 2006). While these studies suggest a positive relationship between the two types of data, although to a varying degree, we argue that, for three main reasons, better insight into the corresponding relationship is required. First, previous studies rely heavily on air passenger flows, which differ from flows of people by other transport modes in that they mainly capture the interaction over very long distances.¹ It is therefore important to extend air passenger flows to cover flows of people by other transport modes.

¹ Long-distance travel by airplane constitutes only 10.4% of all long-distance trips between and within the 15 EU member states in 2001 and Switzerland (own calculation using DATELINE dataset (Dateline Consortium, 2003)).

Second, previous studies often employ only one category of node-attributes such as sociodemographic or economic characteristics. We believe that other important characteristics of nodes, including their sociodemographic, economic, transport accessibility, and tourism profiles, should be examined simultaneously to take account of the fact that urban nodes have multiple functions. Finally, in addition to describing the relationships, it is important to explain possible differences between the two different types of data.

From the literature, various sets of potential factors that may explain the discrepancies between node-attributes and actual interaction can be identified. First, *physical barriers* such as water and sea (Camagni and Salone, 1993) and *non-physical barriers* such as language differences (Rietveld and Jansen, 1990) still play an important part in constraining human corporeal interaction; the presence of such barriers tends to result in lower levels of interaction associated with a node than would be predicted from its attributes. The second factor concerns the *traffic shadow*, referring to the situation in which the role of small nodes is overshadowed by a very large node when located in its proximity owing, for instance, to the wider range of specialised services that a large node offers (Taaffe, 1956). Third, nodes with *functional specialisation*, particularly in financial services and tourism activities, tend to attract more interaction than other nodes in the system (Taaffe, 1956). One possible reason is that there are often very few or even no alternative destinations for highly specialised functions. These sets of potential factors are employed in the empirical analysis to explain possible discrepancies between the positions of nodes using node-attribute and interaction data. In the next section, the datasets are described and some information about the operationalisation of the data is presented.

Research design

Data description

In this study, we have employed data on European long-distance mobility (Dateline Consortium, 2003). The survey was carried out in the 15 Member States of the European Union (in 2001) and Switzerland, starting in June 2001 and covering a period of twelve consecutive months. In this survey, a long-distance journey was defined as a journey to a destination more than 100 km away (as the crow flies); only journeys originating from the respondent's home base have been analysed in this study. Although one may argue that the definition of long-distance travel employed in this database may lead to an underestimation of the interactions between contiguous urban areas, we believe that such effects will be rather small because the distance between most pairs of urban areas in the current study

exceeds the minimum distance of 100 km.² We chose to use the Dateline data for two main reasons. First, it enables us to concentrate on the inter-metropolitan journeys undertaken both within and between many European countries, because the data was collected in much the same manner in all countries. Second, this dataset enables us to compare firm-related business journeys and holiday journeys. By definition, a business journey is a journey made for business purposes. Professional travel by truck drivers, pilots and the like is excluded. A holiday journey is made for holiday purposes, generally longer than three nights away from home.

For the present study, long-distance journeys for business ($n = 12,375$) and holiday journeys ($n = 32,982$) between 39 metropolitan areas in 11 countries were selected: Austria, Belgium, Denmark, France, Germany, Ireland, Italy, the Netherlands, Portugal, Spain, and the UK.³ Although the European core economic zone, which is roughly located between London and Milan, has been the main focus of previous studies (NORDREGIO, 2004), this set of countries was chosen, because we can then have a complete picture of the current pattern of interaction in the European urban system, since countries within and outside the core economic zone of Europe are included.

With respect to node attributes, information on sociodemographic, economic, and part of the tourism characteristics (number of accommodations) was obtained from the REGIO data collected by EUROSTAT (2004). The accessibility measures were computed with GISCO data (European Commission, 2000), which contains both statistical information and geographical information on administrative boundaries and transport infrastructure by road, rail, air, and waterways. The rest of the information on tourism (Table 1) was obtained from the Study Programme on European Spatial Planning (SPESPN) (Fuerst et al., 2000). With respect to the time-period of data collection, the datasets employed are considered highly comparable, because most of the data was collected in 2001. Although the tourism information from SPESPN dates from 1996, these tourism characteristics are unlikely to have changed substantially over such a short time-period.

² Only for 1.33% of all possible connections between NUTS-3 regions located in different metropolitan areas is the distance below 100 km.

³ On average around 1064 respondents were available per metropolitan area. The area with a rather low number of respondents (less than 300) is Salzburg and Innsbruck. With regard to business journeys, on average around 320 respondents who made at least one long-distance journey for business purpose were available per metropolitan area; metropolitan areas with rather low numbers of business travellers are the Spanish regions and Salzburg and Innsbruck. Full information about the number of respondents per metropolitan area is available upon request from the authors.

Table 1 Node-attribute variables per category

Node attributes	Descriptions
<i>Sociodemographic</i>	
Population size	No. of inhabitants in a given metropolitan area
Active population and education attainment	Active population (age between 24 and 65) with tertiary education as a percentage of the total population residing in a given metropolitan area
<i>Accessibility</i>	
Accessibility by highway network	No. of population residing in the 39 metropolitan areas that can be reached within four hours (with an average speed of 100 km/h) via the highway network
Accessibility by high-speed rail network	No. of stations located in the 39 metropolitan areas that can be reached within four hours (with an average speed of 150 km/h) via the high-speed rail network; set to zero if a given metropolitan area has no access to the network
Accessibility by air	No. of airports located in the 39 metropolitan areas that can be reached from the airport(s) located in a given metropolitan area
<i>Economic</i>	
GDP	GDP per capita of a given metropolitan area
Employment in knowledge-intensive service sector	Employment in knowledge-intensive service sector as a percentage of the total employment within a given metropolitan area
<i>Tourism</i>	
Number of accommodations	No. of hotels and similar establishments in a given metropolitan area
Number of registered cultural sites	No. of registered cultural sites within a given metropolitan area
Length of seashore	The length of seashore in kilometre within a given metropolitan area
Annual sunshine radiation	The average annual sunshine radiation within a given metropolitan area (kW h/m ²)

Delimitation of metropolitan areas

In this study, the metropolitan areas were operationalised via the concept of functional urban regions (FURs) to represent the spatial units that are functionally interrelated in economic terms, because these can be compared with one another more easily (NORDREGIO, 2004). However, the delimitation of such areas is constrained by the availability of data in at least two respects. First, the functional interdependencies should ideally be derived from interaction data such as daily commuter flows. For many countries in the study area we do not have access to such data, so we have defined the metropolitan areas on the basis of five variables from EUROSTAT (REGIO) measured at the NUTS-3⁴ level for Belgium, France, the Netherlands, Germany, and the UK: the ratio of jobs to the size of the active population; the number of jobs; job density; the number of inhabitants; population density (see Limtanakool et al., 2007 for more details). Second, because the REGIO data is not fully complete at the NUTS-3 level for Austria, Denmark, Ireland, Italy, Portugal and Spain, we have had to rely on information at NUTS-2 level for these countries. The demarcation of metropolitan areas was carried out by first identifying densely populated cities in each country and then selecting the NUTS level-2 region(s) to which these major cities belong. Finally,

the boundaries of metropolitan areas defined at the NUTS-3 level were adjusted to match those of NUTS-2 level areas to make them comparable with Austria, Denmark, and so forth.

Data operationalisation

As far as the interaction approach is concerned, we conceptualise metropolitan areas as nodes in the network connected to one another via flows of people. In the theoretical framework section, we noted that the strength and connectivity are relevant for the position of a node in the urban system. Accordingly, the *Dominance index* has been devised to measure the strength of interaction associated with a node, and the *Entropy index* to measure the connectivity of a node (Table 2). The dominance index is defined as the ratio between the (total or incoming) interaction associated with the node *i* and the average size of its (total or incoming) interaction associated with other nodes in the network. The entropy index measures the extent to which the interaction is distributed evenly across the links associated with node *i*. This index varies from 0 to 1, with 1 indicating that the interaction on all links associated with node *i* is equally strong. A node at the top of an urban hierarchy is expected to possess a high score on both indices.

For both indicators we take into account the directionality of flow for holiday flows, because it is clear that the holiday journeys were undertaken for acquiring products or services tied to specific destinations. However, since the data employed do not allow a detailed distinction to be drawn in the types of activity pursued during business journeys, the importance of the node and the directionality of flows are less clear-cut for business flows; such

⁴ The Nomenclature of the Territorial Units for Statistics (NUTS) is a hierarchical classification, which was set up to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union. The size of NUTS-1 level, as defined in terms of the number of inhabitants, is between 3 and 7 million inhabitants, whereas that of NUTS-3 level is between 150,000 and 800,000 inhabitants.

Table 2 Description of the interaction indices

	Dominance (DIT_i and DII_i)	Entropy (EIT_i and EII_i)
Equation	$DIT_i = \frac{T_i}{(\sum_{j=1}^J T_j/J)}$ $DII_i = \frac{I_i}{(\sum_{j=1}^J I_j/J)}$	$EIT_i = - \sum_{l=1}^L \frac{(x_l)Ln(x_l)}{Ln(L)}$ $EII_i = - \sum_{l=1}^L \frac{(y_l)Ln(y_l)}{Ln(L)}$ <p>for $x = 0$ holds that $(x)Ln(x) = 0$ for $y = 0$ holds that $(y)Ln(y) = 0$</p>
Min/Max value	$0 \leq DIT_i$ and $DII_i \leq \infty$	$0 \leq EIT_i$ and $EII_i \leq 1$

Denotation
 DIT_i and DII_i Dominance index on total and incoming interaction

 EIT_i and EII_i Entropy index on total and incoming interaction

 T_i and T_j The total number of journeys associated with node i and j
 I_i and I_j The number of inward journeys to node i and j
 l Link associated with node i ($l = 1, 2, 3, \dots, L$)

 x_l Proportion of total journeys on link l in relation to the total number of journeys associated with node i
 y_l Proportion of incoming journeys on link l in relation to the total number of incoming journeys associated with node i
 i and j $i = 1, 2, 3, \dots, I; j = 1, 2, 3, \dots, J; \text{ for } i \neq j$

journeys can be undertaken not only for acquiring products and services, but also for offering services. We have therefore employed the dominance and the entropy indices on total interaction (DIT_i and EIT_i) for business (the total interaction is defined as the sum of the incoming and outgoing flows to and from a given node), and on incoming interaction (DII_i and EII_i) for holiday purposes.

With respect to the node-attribute data, four categories of variables are employed to represent the characteristics of metropolitan areas: sociodemographic, transport accessibility, economic, and tourism indicators. *Table 1* reveals how these variables are measured. The sociodemographic factors and accessibility measures are used for both business and holiday journeys. The economic dimension is only employed for business flows; the tourism variables are only employed for holiday flows. Although some variables such as the number of hotels and similar establishments may be associated with both business and holiday journeys, the variables are only employed for holiday journeys, because their relationship with the holiday journeys is likely to be considerably stronger.

Deriving the ranking of the metropolitan areas

To rank metropolitan areas, we used the Borda ranking, which is a composite index that requires the aggregation of the rank orders of objects (metropolitan areas for example) and individual attributes (number of inhabitants for example) (Satya, 1997). The Borda ranking was preferred, because it always gives a definite ranking, and uses ranking information fully and systematically. Another justification is that the Borda ranking possesses the property of

Pareto optimality, which means that if metropolitan area i performs better than metropolitan area j in terms of all the attributes, metropolitan area j will not be ranked above i (Satya, 1997). The Borda score is calculated as follows: if n is the number of metropolitan areas and m the number of attributes of the urban ranking, then the Borda score of metropolitan area i is given by

$$B^i = \sum_{k=1}^m (n - a_k^i), \quad (1)$$

where a_k^i is the rank order of metropolitan area i with respect to attribute k ; with $B^i = 1, 2, 3, \dots, n$. The metropolitan area performing best with respect to k scores $n - 1$; that performing second best $n - 2$, and so on, until the metropolitan area with the worst performance acquires a score of zero. Summing over all the attributes gives the total Borda score for metropolitan area i , the metropolitan area with the highest score ranks first and so on in downward order. In this way, Borda ranking allows a good performance for one attribute to compensate for poor performance with respect to another attribute, since it is the total Borda score that counts (Satya, 1997). The outcomes of the ranking exercise are influenced by the choice of variables when the number of variable is small, as is the case in our study. During the analysis, we explored many different rankings and used two main criteria for determining the set of outcomes presented in this paper: the choice of variables should be theory-driven and the resultant Borda ranking should be intuitively plausible.

In this study, metropolitan areas are ranked at two different levels according to their Borda scores. At the lower level, metropolitan areas are ranked

according to the (sum of) the Borda scores of individual members of each category. After we obtain six sets of Borda rankings (i.e. two for interaction data and the rest for the node characteristics data), the Borda score for each metropolitan area are summed and ranked per type of data. This yields at the end two sets of rankings: the overall interaction and the overall attribute rankings. Furthermore, the Spearman rank correlation coefficient is employed to measure the strength of the associations between the ranks of the metropolitan areas, because this statistic is robust to outliers and does not require normally-distributed observations. The coefficient ranges from -1 to $+1$; the closer the correlation is to either -1 or $+1$, the stronger is the relationship. Generally speaking, a correlation above 0.60 indicates a relationship between two sets of data.

Least squares regression analysis

In the theoretical section, we noted that barriers, traffic shadow, and the specialisation of places were expected to explain the differences between interaction and node-attribute rankings. Three regression models were estimated per journey purpose (that is, models B1–B3 and H1–H3 for business and holiday journeys, respectively (*Table 3*)). The three models differ from one another with respect to the dependent variable employed. The first model takes the difference in rank order (that is, the rank derived from the interaction data minus that from the node-attribute data) as the dependent variable. The second (third) model uses the node-attribute (interaction) rank as the dependent variable, and the interaction (node-attribute) rank as independent variable. We included node-attribute (or interaction) rank as one of the independent variables in order to examine the influence of other factors after controlling for its relationship with the interaction (or node-attribute) rank. The stepwise method was employed to allow only the variables that were statistically significant at the 95% confidence interval to enter the final models; this method was used to maximise the degrees of freedom, which is important for the reliability of the models, particularly with a small number of observations.

In addition to barriers, traffic shadow, and the specialisation of places, we hypothesised that the delimitation of the study area might affect the level of interaction associated with a node (*Table 3*). For instance, the interaction associated with a node located at the fringe of the study area might be lower than the actual level, because the important partners of the node might be excluded from the study area. It is therefore important to examine whether the discrepancies between two different types of data are an artefact of the delimitation of the study area. While physical barriers, the traffic shadow – as measured by the average distance to

London and Paris, the two main European metropolitan areas – and the effect of the delimitation of the study area were allowed to be included as independent variables in every model, some additional variables were also suitable for either business or holiday journeys. Language barriers and specialisation in financial services were employed only for business journeys, while climate and types of scenery were used for holiday journeys. The variable of language barrier was not used for holiday journeys because it is highly correlated with the climate variable ($r = 0.81$).

A comparison of ranks of metropolitan areas using interaction- and node-attribute data

In this section, we describe how the rankings of the metropolitan areas using interaction- and node-attribute data relate to each other, and how the differences between the two can be explained. We do so separately for business and holiday interaction data and node attributes. Since both the overall interaction and the overall node-attribute rankings are made up of several elements (the dominance and entropy indices) and dimensions (sociodemographic, accessibility, economic, and tourism node characteristics) respectively, the information for each of these rankings is a stepping-stone to the understanding of the relationship between the two overall rankings. For this reason, we start the discussion by examining each of these individual rankings and how they are related to one another. More detailed information on the ranks of individual metropolitan areas per element/dimension is given where appropriate. Finally, we discuss the correlation between the overall interaction and overall node-attribute rankings.

Business interaction data and node attributes

With respect to the relationship between the interaction indices rankings, *Table 4* shows that the *dominance* and *entropy* rankings are moderately related to one another, as the correlation coefficient of 0.45 indicates. We find that 8 of the 10 best performers appear on the rankings of both the dominance and entropy indices: Paris, Hanover-Bremen, Rhine-Mainz, and Stuttgart for example (see *Table 5*). However, we also observe differences between the two rankings for the metropolitan areas of London, the Midlands, and Milan. This division indicates that nodes do not necessarily hold an important position on both aspects simultaneously. These differences justify a more thorough discussion of the rankings of individual metropolitan areas.

On examining the ranks of individual metropolitan areas per interaction index, we see that the top ranking metropolitan areas on the dominance index tend to be large urbanised areas such as London, Paris, the Midlands, Hanover-Bremen, and Rhine-Mainz (see *Table 5*). These metropolitan areas in

Table 3 Specifications and results of regression models for business and holiday flows

Independent variables	Business flows			Holiday flows		
	B1	B2	B3	H1	H2	H3
	Dependent variables					
	Difference in ranks	Rank: node attribute	Rank: interaction	Difference in ranks	Rank: node attribute	Rank: interaction
1. Barriers						
Physical: a metropolitan area is located on the mainland Europe or not	(0.41)**	(-0.23)**	(0.23)**	(0.53)**	X	(0.44)**
Language: language speaking by inhabitants of a metropolitan area is in the Romanic or Germanic family	X	X	X			
2. Traffic shadow						
Average distance from a metropolitan area to London and Paris	X	X	X	X	(0.34)**	X
3. Specialisation of places						
In financial services: percentage of employment in financial service in relation to the total employment within a metropolitan area	X	X	X			
In tourism activities: a metropolitan area located below the latitude 45 north is considered to have a Mediterranean climate				X	X	X
In tourism activities: a metropolitan area is characterised as a mountainous area				X	X	X
In tourism activities: a metropolitan area is characterised as a coastal area				(-0.29)**	X	(-0.21)*
4. Effect of the delimitation of the study area						
Distance from a metropolitan to the centre of the study area	X	X	X	X	X	X
5. Rank of metropolitan areas						
Using node-attribute data			(0.84)**			(0.63)**
Using interaction data		(0.85)**			(0.54)**	

Note: Numbers between brackets are the standardised coefficient of variables included in the final stepwise regression models.

X represents independent variables that were not statistically significant in the final model specifications.

*Results are significant at 85% confidence interval.

**Results are significant at 95% confidence interval.

Table 4 Correlation between rankings of metropolitan areas: Business flows

	Interaction index			Node attributes			
	Dominance	Entropy	Overall: interaction indices	Sociodemographic	Accessibility	Economic	Overall: node attributes
<i>Interaction index</i>							
Dominance							
Entropy	0.45						
Overall: interaction indices	–	–					
<i>Node attributes</i>							
Sociodemographic	0.67	0.52	0.70				
Accessibility	0.79	0.64	0.85	0.62			
Economic	0.55	0.53	0.62	0.63	0.57		
Overall: node attributes	0.75	0.66	0.81	–	–	–	

countries such as France, Germany and the UK have a prominent role in the world economy as well as in Europe. In contrast, metropolitan areas located on the fringe of our study area such as Copenhagen, Dublin and Southern Ireland, Lisbon, and Porto have little interaction with other metropolitan areas. Unfortunately, we were not able to conduct a full test to see whether this result was an artefact of the chosen delimitation of the study area. This constraint stems from the lack of information on the journeys originating from countries other than the 16 countries in which the surveys were conducted. We have, however, investigated the magnitude of the flows sent from the three metropolitan areas (Berlin, Vienna, and Copenhagen) located furthest to the east of the study area and found that less than 20% of the outgoing flows from these metropolitan areas were to countries outside the study area. This finding suggests that the positions of these metropolitan areas would have been unlikely to change much had countries in Eastern Europe been explicitly incorporated in the study area. Collectively, the results suggest that the ranking of metropolitan areas using the dominance index tends to be influenced by the size of the metropolitan area. For the entropy index ranking, the top ranking metropolitan areas are those located centrally in our study area, such as the Randstad, and the Rhine-Ruhr area.

Turning to the relationships among node-attribute rankings, the estimated correlation coefficients show that the *sociodemographic*, *accessibility*, and *economic* attributes are clearly related to each other (Table 4). The sociodemographic-attributes ranking shows that the metropolitan areas in which capital cities are located appear at the top of the ranking, such as London, Paris, and Berlin (Table 5). Metropolitan areas located centrally in Europe, such as the Rhine-Ruhr area and the Randstad, appear at the top of the accessibility ranking. This finding suggests that metropolitan areas benefit from a central location within transport infrastructure networks, which gives them a locational advantage over other metropolitan areas. The level of accessibility seems to

decrease as we move southwards, although Milan is an exception in this respect. The relatively low positions of Copenhagen, Dublin and Southern Ireland, and the UK areas may reflect physical barriers imposed by sea. It should, however, be noted that the results reported here are based solely on the level of accessibility among metropolitan areas within the study area. The metropolitan areas located on the fringe, such as Berlin or Vienna, may possibly have a higher level of accessibility if their neighbouring metropolitan areas are included in the study area. This issue cannot, however, be resolved here, because we do not have access to the same sets of transport networks for countries in Eastern Europe. For economic attributes, Paris, London, Copenhagen, Rhine-Mainz, and the Randstad are the top-ranking metropolitan areas, since they are associated with high GDP per capita and a concentration of employment in knowledge-intensive services. Again, the ranking of a metropolitan area tends to decline as we move to the southern part of Europe.

Before turning to the relationship between the overall interaction and the overall node-attribute rankings, we first consider the degree to which the various rankings of the interaction and node attribute data correlate with one another to shed light on the elements that make up the two overall rankings (Table 4). We find that the dominance and entropy indices are the most strongly correlated with accessibility (0.79 and 0.64, respectively); the overall interaction ranking also has the strongest correlation with accessibility attributes (0.85). The strong correlation between the interaction indices and the level of transport accessibility is not surprising, because human corporeal interaction is facilitated, and sometimes determined, by the quality of the transport infrastructure available. Moreover, the fact that the level of accessibility is a derived flow (it is neither pure node-attribute nor actual interaction data) also explains this strong correlation. This finding suggests that accessibility indicators can be a relatively good alternative for ranking metropolitan areas if human corporeal interaction data is not available. However, since different types of flow tend to have different

Table 5 Rankings of metropolitan areas based on the interaction- and node-attribute data

Country	Metropolitan areas	Business flows			Holiday flows			Node attributes					
		Dominance	Entropy	Overall	Dominance	Entropy	Overall	Sociodemographic	Accessibility	Economic	Tourism	Overall business	Overall holiday
Austria	Salzburg and Innsbruck	32	33	35	1	24	8	38	25	26	18	33	31
	Vienna	25	16	19	30	27	31	34	34	6	28	28	35
Benelux	Brussels-Antwerp	12	15	11	22	2	6	3	5	13	31	4	10
	Halfwegzone	18	20	15	16	20	19	20	11	7	32	12	22
	Maastricht-Aachen-Liege	8	9	7	19	13	15	18	4	13	34	9	16
	The Randstad	10	1	3	14	8	4	4	2	5	23	3	7
Denmark	Copenhagen	37	11	27	38	3	25	12	27	3	20	13	18
France	Lille	17	37	29	31	33	36	31	15	37	39	30	34
	Lyon	14	32	22	6	23	12	14	20	29	22	20	18
	Marseille-Nice	20	17	14	4	21	8	24	18	30	8	26	13
	Nantes	31	34	35	20	35	30	32	36	35	34	37	36
	Paris	2	6	1	7	9	2	1	6	1	19	1	4
	Strasbourg	23	23	22	25	25	28	28	17	27	34	27	33
	Toulouse-Bordeaux	22	25	26	8	26	18	20	30	19	11	22	17
Germany	Anhalt	13	21	13	24	16	24	18	16	36	24	24	20
	Berlin	7	10	7	18	19	20	4	19	23	38	14	26
	Hanover-Bremen	4	4	1	15	10	8	16	3	13	15	8	9
	Munich	11	7	9	10	15	8	11	10	8	7	11	7
	Nuremberg	21	19	18	35	28	34	30	12	16	27	17	27
	Rhine-Mainz	5	8	6	23	7	13	8	9	4	10	6	6
	Rhine-Ruhr	9	2	3	32	18	28	12	1	11	8	5	2
	Stuttgart	6	5	3	12	12	6	4	7	8	6	7	3
Italy	Florence	28	18	22	17	5	4	36	27	24	4	31	23
	Milan	16	3	10	28	11	23	22	12	21	15	16	15
	Naples	33	24	31	29	14	26	27	37	32	21	36	32
	Rome	24	22	22	27	4	14	28	32	30	15	31	28
	Turin	27	14	19	21	17	22	26	20	20	3	24	13
	Venice	29	28	31	13	1	1	35	20	24	14	29	24
Ireland	Dublin and Southern Ireland	36	31	37	33	30	34	23	30	16	12	21	21
Portugal	Lisbon	39	39	39	39	39	39	36	38	34	32	38	38
	Porto	38	30	38	36	22	32	39	39	39	30	39	39
Spain	Barcelona	30	13	21	11	6	3	9	24	32	12	22	12
	Madrid	26	12	15	34	38	37	9	25	18	29	15	24
	Seville, Granada, Malaga	34	29	34	3	29	15	17	23	22	2	18	10
	Valencia	35	27	33	5	32	20	25	29	38	25	34	30
UK	Glasgow-Edinburgh	19	36	30	26	34	33	15	35	12	25	18	29
	London-South UK	1	26	11	2	31	17	1	8	2	1	2	1
	Midlands-Northwest	3	35	15	9	37	27	4	12	8	4	10	5
	Northern region (Tyneside)	15	38	28	37	36	38	33	33	28	37	35	36

characteristics, this finding cannot be directly transposed to other types of interaction data. A relatively high correlation is also found between the dominance index and the demographic attributes (0.67). If one wishes to focus purely on the volume of interaction, the demographic attributes of metropolitan areas can be considered a reasonably good alternative for deriving rankings. Although one might expect a strong correlation between the business interaction data and economic attribute rankings, our results show that the relationship is not as strong as that between the interaction and accessibility

rankings. This weaker relationship suggests that the economic attributes alone would not have been a good proxy for deriving the metropolitan areas' ranking from an interaction perspective, at least for the current study (see *Figure 1*).

Having considered each of the individual rankings that constitute the overall interaction and overall node-attribute rankings, we now turn to the correlation coefficients between the two overall rankings (*Table 4*). Interestingly, we find a rather high correlation for these two overall rankings (0.81), suggesting that they are good proxies for one another. The

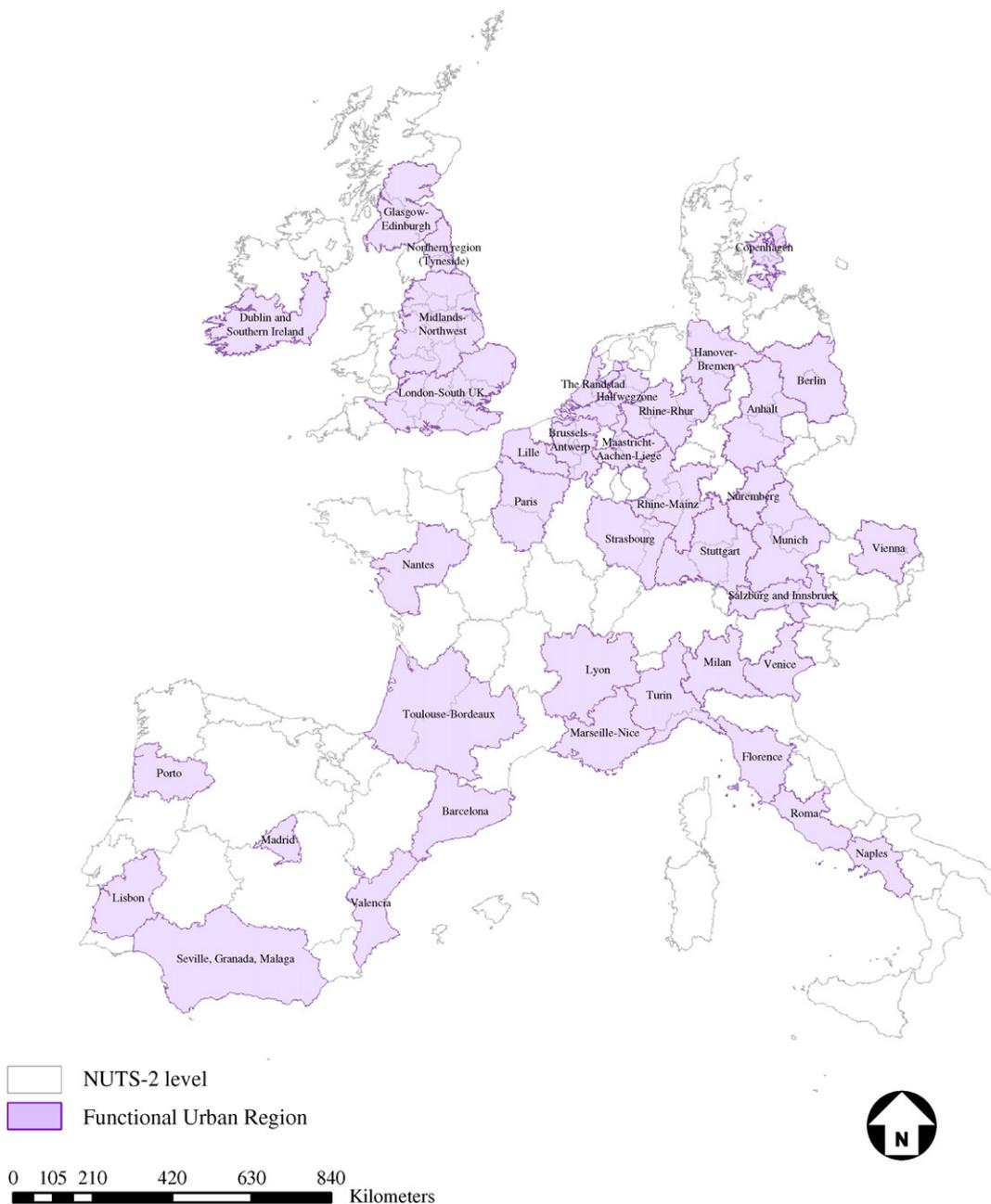


Figure 1 Thirty-nine metropolitan areas in the study area.

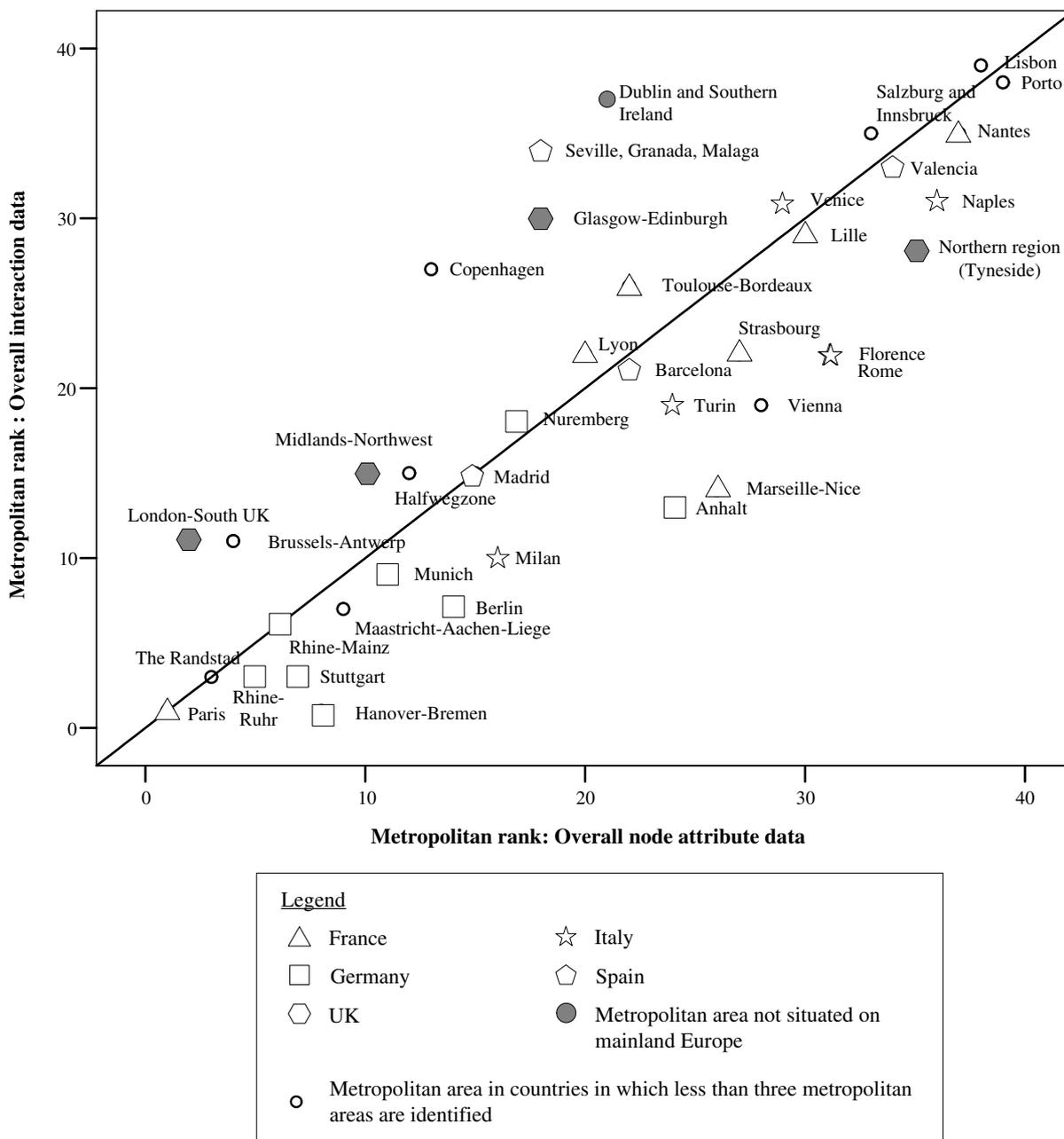


Figure 2 Correlation between overall interaction and node-attribute rankings: Business flows.

rankings using these two types of data are plotted against each other in *Figure 2*. Metropolitan areas above (or below) the diagonal line have their positions underestimated (or overestimated) by the interaction data in relation to node attributes. Since the metropolitan areas located within the same country share many similarities, we discuss the results by country. We find that most German metropolitan areas hold rather high positions on both rankings, as they are concentrated on the bottom-left of the figure. Nevertheless, we find that the positions of metropolitan areas in Germany tend to be underestimated by node attributes. One underlying

reason appears to be the well-balanced system of medium-sized and large metropolitan areas with markedly specialised economic functions (Bremm and Ache, 1993). Since the interaction between metropolitan areas is primarily structured by their functional differentiations, the specialisations of the German metropolitan areas may lead to intense exchanges between them (Janelle, 1969). For France, the primacy of Paris in the urban system is clearly shown on both rankings. We may observe a large gap between Paris and other French metropolitan areas, which tend to occupy positions in the lower echelons. Similar gaps are found for Italy and Spain,

where Milan and Madrid are the only metropolitan areas appearing in the higher echelons (Table 5).

Figure 2 shows that node attributes tend to overestimate the importance of metropolitan areas that are not situated on mainland Europe, namely London, the Midlands, Glasgow-Edinburgh, and Dublin and Southern Ireland. These metropolitan areas function as central nodes in their national economies and hold high positions on the economic attributes, but have weaker relationships with metropolitan areas on mainland Europe. This contrast suggests that the physical barriers imposed by sea play a part in limiting the interaction between metropolitan areas as far as corporeal travel is concerned.

The effect of physical barriers is confirmed by all three regression models (Table 3). The results show that physical barriers increase the discrepancies between the two overall rankings by lowering the levels of interaction associated with nodes. Models B2 and B3 also confirm the strong relationships between the interaction and node-attribute rankings. Furthermore, neither language barriers, traffic shadow, specialisation in financial service, nor the delimitation of the study area are statistically significant in explaining the ranks of metropolitan areas after controlling for the effect of interaction rankings in model B2 and node-attribute rankings in model B3. While the lack of significance of the delimitation of the study area confirms our preliminary investigation reported earlier, the lack of significance of the specialisation in financial service of metropolitan areas in all models is not in line with our expectations. This result may suggest that employment in the financial service sector alone is not sufficient to explain the positions of metropolitan areas on the two overall rankings, at least for the current data. In addition, further analysis has suggested that the variables ‘language’ and ‘traffic shadow’ affect the positions of nodes on both rankings in much the same manner. It can therefore be concluded that these variables do not affect the differences between the two rankings.

Holiday flows and node attributes

The discussion of the results for the holiday interaction and node-attributes data follows the same structure as that of the business results. Between interaction indices, we find that the correlation between the *dominance* and *entropy* indices rankings is very low (0.12), much lower than that found in the case of business travel (Table 6). This lower correlation is clearly borne out when we examine the ranks of individual metropolitan areas by interaction index (see Table 5). Metropolitan areas such as Salzburg and Innsbruck, London, and Seville receive many holiday journeys, but the flows are concentrated on just a few links, typically those with the capital of the country in which they are located. This pattern may point at the important role of culture and language in structuring holiday flows. Furthermore, major holiday destinations based on the dominance index tend to be the metropolitan areas situated in the southern part of Europe such as Salzburg and Innsbruck, Seville, and Marseille-Nice (Table 5). For the entropy index, we find that all six of the metropolitan areas in Italy are in the top 15. This ranking suggests that these metropolitan areas attract holiday flows from many directions, and the distribution of flow across links attached to them is fairly even. Nevertheless, the total amount of journeys received by these metropolitan areas is not very large. With respect to the relationships among node-attribute rankings, Table 6 shows that the correlation coefficients between the tourism and the sociodemographic rankings (0.27) and the tourism and the accessibility rankings (0.22) are rather low. This suggests that the widely-used sociodemographic and accessibility attributes are not good proxies for representing the attractiveness of areas as tourism destinations, at least for the set of tourism attributes employed in this study. It is therefore important to draw a distinction between the tourism-attribute ranking and the overall holiday ranking.

With respect to individual node-attribute rankings, we only discuss the *tourism* ranking here, since the sociodemographic- and accessibility-attributes

Table 6 Correlation between rankings of metropolitan areas: Holiday flows

	Interaction index			Node attributes			
	Dominance	Entropy	Overall: interaction indices	Sociodemographic	Accessibility	Tourism	Overall: node attributes
<i>Interaction index</i>							
Dominance							
Entropy	0.12						
Overall: interaction indices	–	–					
<i>Node attributes</i>							
Sociodemographic	0.34	0.23	0.35				
Accessibility	0.33	0.38	0.47	0.62			
Tourism	0.48	0.27	0.47	0.27	0.22		
Overall: node attributes	0.49	0.41	0.58	–	–	–	

rankings have been previously discussed. We find that London, Seville, Turin, and Florence rank highest on the basis of tourism attributes. Generally speaking, metropolitan areas holding high positions on tourism ranking tend to be located in the southern part of Europe (see Table 5). This finding is similar to that reported earlier on the dominance index ranking.

We now turn to the relationships among the rankings based on interaction- and node-attribute data. In contrast with business journeys, the sociodemographic and accessibility attributes do not show a strong relationship with the holiday flows (the corre-

lation coefficients are below 0.50). These attributes would therefore not be a good proxy for deriving the ranking from an interaction perspective and vice versa. The strong correlation between accessibility attributes and interaction data reported previously seems to be specific to the business flows. On the basis of our results, we report that we have not found a set of node attributes that could be generalised to both business- and holiday-interaction data.

The rankings of metropolitan areas derived from the overall interaction and overall attribute data are plotted against each other in Figure 3. The correlation coefficient of 0.58 indicates a moderate

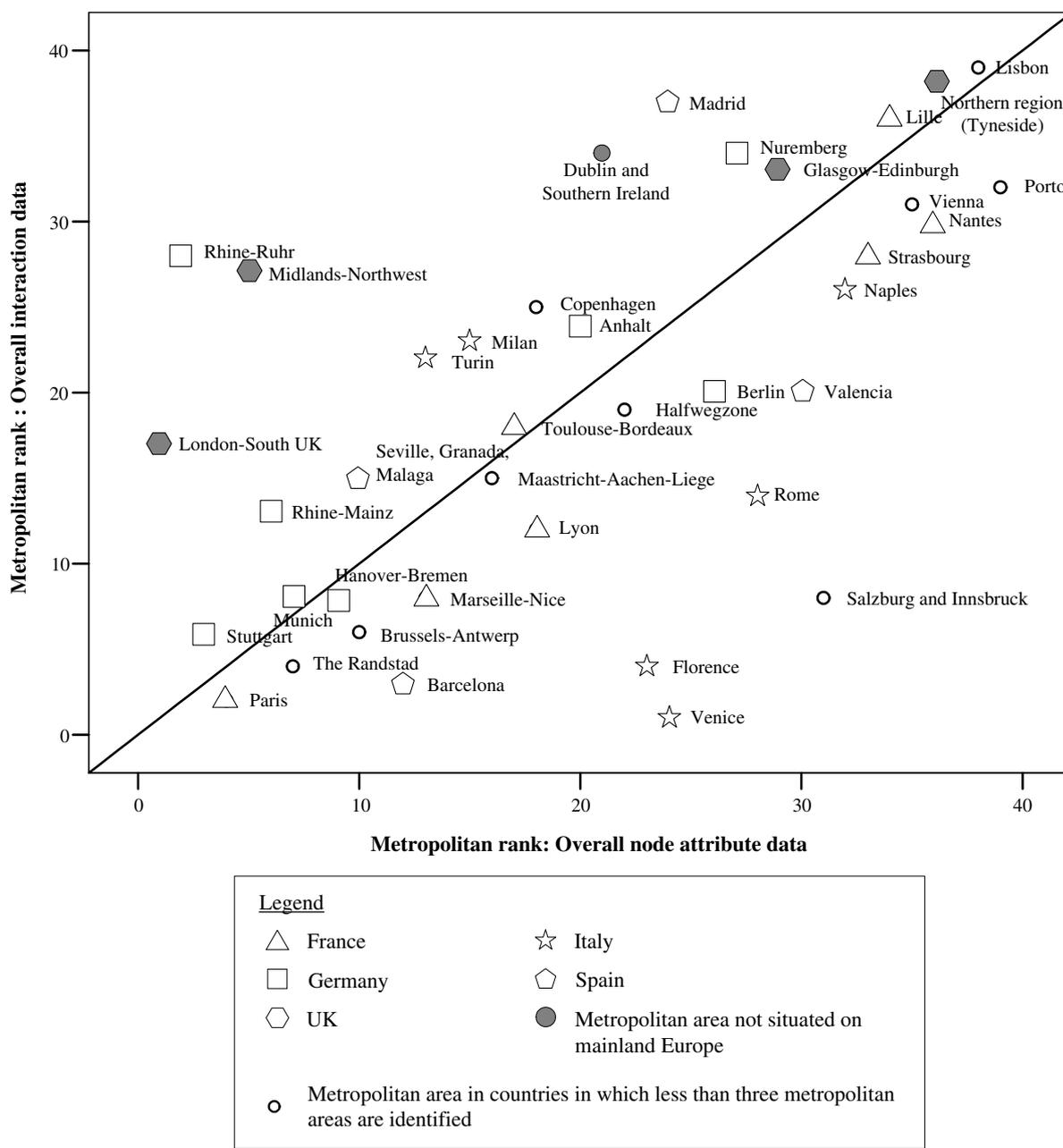


Figure 3 Correlation between overall interaction and node-attribute rankings: Holiday flows.

relationship (Table 6). In contrast with business journeys, we have not detected a pattern of variation by country, but rather by the location of metropolitan areas within Europe. Figure 3 shows that most metropolitan areas in southern Europe are below the diagonal line, suggesting that their positions on the rankings by interaction tend to be overestimated. This finding might partially reflect the relationships of complementarity between metropolitan areas located in Southern Europe with respect to their tourism functions. The attractiveness of these destinations may be enhanced when they are located in proximity to many attractions (Fik et al., 1992; Fotheringham, 1984).

Furthermore, we find that the role of the Rhine-Ruhr area is overestimated by the overall node-attribute data. The fact that we have only examined inter-urban, but not intra-urban, holiday flows might be the reason for this overestimation. Metropolitan areas such as the Rhine-Ruhr region might contain many resources that are mainly used by their inhabitants. As a result, there could be a large discrepancy between the rankings of metropolitan areas when using two different types of data. Above the diagonal line, the importance of the metropolitan areas detached from mainland Europe (e.g. Glasgow-Edinburgh, and Dublin and Southern Ireland) appears to be overestimated by node attributes from an interaction perspective.

As with the business flows, model H1 confirms the effect of physical barriers on the discrepancies between the overall node-attributes and overall interaction rankings for holiday flows (Table 3). Furthermore, the negative coefficient of the variable 'coastal area' in model H1 suggests that differences between the two overall rankings tend to be larger when metropolitan areas are characterised as coastal areas; metropolitan areas characterised as coastal areas tend to receive more holiday flows than would be predicted on the basis of their internal characteristics (model H3). The variable 'coastal area' in model H3 is, however, only significant at the 85% confidence level.

Models H2 and H3 also confirm the relationships between the two overall rankings, although the relationships are not as strong as that reported for business flows. Furthermore, model H2 shows that the 'traffic shadow' variable is positively related to the overall node-attributes ranking, suggesting that the overall node-attribute ranking increases when the location of a metropolitan area is further away from London and Paris. This result tends to reflect the concentration of the sociodemographic and high levels of accessibility in the central area of Western Europe.

Conclusion

In this study, we have considered to what extent the rankings of metropolitan areas using interaction-

and node-attribute data are correlated. Data on European long-distance passenger mobility (Date-line Consortium, 2003) and the attributes of the metropolitan areas (EUROSTAT, 2004) have been used to generate the rankings of 39 metropolitan areas in 11 countries in Europe.

The results confirm the relationships between the interaction- and node-attribute data. The physical barriers imposed by sea were an important factor underlying the differences between rankings derived from human corporeal interaction- and node-attribute data, as the regression results indicated. Differences can, however, be observed between business and holiday flows. In comparison with holiday flows, business flows show stronger correlations with node-attribute data. Accessibility attributes were found to correlate with business flows, while tourism attributes correlate with holiday flows. Furthermore, we found that the difference between the node-attribute and interaction rankings can be explained not only by physical barriers for holiday flows, but also by specialisation in the tourism function in coastal areas. Other sets of factors – specialisation in financial services, language barriers, and traffic shadow – that were expected to be capable of explaining the difference between the rankings did not emerge as statistically significant in any of the regression analysis conducted.

There may be some other reasons underlying the differences between interaction and node-attribute rankings. First, the relationships between the interaction and attributes of nodes may occur with a lag rather than contemporaneously. For instance, the adaptations in the levels of human corporeal interaction between areas to changes in the attributes of nodes could be more immediate, especially for holiday flows, than for the reverse direction, because node attributes tend to exhibit a strong degree of persistence and continuity (Batty, 1998). Second, the roles of nodes on multiple spatial scales ranging from the metropolitan via the national and European to the global level are reflected in the attributes of a node, but this multiplicity is not fully captured by interaction data limited to a single geographical level as in the current paper. This difference may partially explain why the interaction and node-attribute rankings do not map completely onto another, and calls for the use of interaction data that can measure the importance of a node at multiple geographical levels in future research. Third, some interventions by, for instance, public authorities at various administrative levels may, through rules and regulations in market processes, distort the spatial reconfigurations of node attributes and flows. These issues await further study to advance our understanding of the relationships between interaction- and node-attribute data.

Analysing flows of people using different transport modes reveals the importance of many metropolitan areas that would not have been recognised

had only air passenger flows been analysed. Midlands-Northwest, for instance, is an area that interacts intensively with London and appears very high on both node-attribute and interaction rankings when all transport modes are considered. However, the geographical distance between Midlands-Northwest and London is of magnitude for which air travel cannot compete very well with other transport modes. Relying only on air passenger flows may therefore lead one to underestimate the importance of metropolitan areas, particularly among those located in proximity to one another.

Furthermore, additional research using different types of interaction- and node-attribute data is required, because only corporeal long-distance journeys between metropolitan areas have been analysed in this study. Different conclusions might have been drawn if different sets of interaction- and node-attributes data had been employed. In particular, more intangible node-attributes such as the quality of life and a city's image are important for determining economic growth (Wong, 1998) and deserve special attention in further research. They may be capable of explaining part of the remaining variations that cannot be captured by the standard set of node-attributes. In addition, using more than one type of flow data, such as human corporeal interaction and flow of information, may allow us to explain more fully the variations between interaction and attributes of nodes. For instance, if flows of information and people can be substituted for one another, the levels of interaction associated with nodes may be lower than would be predicted by their internal characteristics had only flows of people been analysed. Furthermore, further research should focus on the actors, because individuals, firms, and planning authorities mediate the interaction and node-attributes. Changes in their actions would result in the reconfigurations of flows and node attributes within the urban system.

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