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A Theoretical Framework and Methodology for Characterising National Urban Systems on the Basis of Flows of People: Empirical Evidence for France and Germany

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Summary. In advanced economies, flows play an important part in connecting urban nodes. This paper sets up a framework for identifying and classifying the pattern of the urban systems from an interaction perspective. Three S-dimensions are proposed (that is, the strength of interaction, the symmetry of interaction and the structure of the network) and a set of indices that are important for characterising network configurations. Using the European long-distance mobility database (DATELINE), the framework is applied to examine the pattern of interaction between functional urban areas (FURs) in France and Germany. The analysis is carried out separately for three journey purposes: business, holiday and leisure. The results reveal that national urban systems embrace a wide variety of constellations and that considerable variation in these constellations can be observed across journey purposes and countries. Overall, the authors are confident that the proposed framework provides a useful analytical tool for characterising the configurations of urban systems.

1. Introduction

Driven by innovations in transport and communication technologies and economic prosperity, the spatial organisation of the economic activities of firms and the social activities of individuals and their households has extended spatially. A transition in urban spatial structure has occurred and been observed at various geographical scales in the past few decades. The presence of multiple centres with specialised economic, social and cultural functions and a high degree of interaction between them makes a monocentric model no longer suitable to describe contemporary urban configurations at the metropolitan level (Clark and Kuijpers-Linde, 1994; Kloosterman and Musterd, 2001). The same transition is also evident at the higher spatial scales (Dieleman and Faludi, 1998). The individual metropolitan areas increasingly function as nodes that connect to one another via various types of flows in wider urban systems such as the national urban systems and the world cities system (Beaverstock *et al.*, 2000; Taylor, 2004). However, relatively little is known as to how the structural configurations of systems at the national or international level can be characterised.

Nowadays, the properties of urban nodes are frequently determined by relations and

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flows within networks; these properties are more a function of what flows through cities than what is fixed within them (Smith, 2003). We therefore believe that a theoretical framework for characterising the structural configurations of urban networks should be premised on interaction within networks. Although research concentrating on interaction is quite common at the metropolitan level (Clark and Kuijpers-Linde, 1994; van der Laan, 1998) and the global level (for example, Beaverstock *et al.*, 2000; Taylor, 2004), there are few studies at the intermetropolitan level that employ relational data and put flows at the heart of their empirical analysis (van der Laan, 1998). This study therefore focuses explicitly on this spatial scale. The fact that so few studies have explicitly employed an interaction perspective is to a large extent the result of the lack of suitable data sources.

This study therefore seeks to contribute to the scientific literature by proposing a framework to classify and characterise the configurations of urban systems from an interaction perspective, a framework which can be used at different spatial scales, including the intermetropolitan level. In this study, we draw on concepts of monocentric and polycentric systems from studies at the metropolitan level to describe configurations of urban systems at the intermetropolitan level. In so doing, we first address the three S-dimensions of spatial interaction that can be used to characterise urban systems—namely, the strength of interaction, the level of symmetry and the structure of the system. Secondly, a set of indicators for describing the patterns of spatial interaction according to the three important dimensions is proposed. Thirdly, we illustrate the proposed framework by empirical data from the European long-distance travel mobility database (Dateline Consortium, 2003a) to characterise the French and German national urban networks, which include several functional urban areas (FURs). These two countries have been chosen because their contrasting urban constellations—a centralised system in France with the primacy of Paris and a rather well-balanced system with multiple centres in Germany—enable us to assess the utility of our approach in both sets of circumstances.

Although the interaction among spatial units takes multiple forms such as flows of people, goods, information and money (Pred, 1977), we focus on corporeal human interactions, because face-to-face relationships continue to be important in the development of urban networks, despite the telecommunication revolution (Smith and Timberlake, 2001). More specifically, in this study we focus on the flow of people travelling between distinct functional urban regions (FURs) because it is the less frequent journeys undertaken over greater spatial distances than daily (commuting) journeys that are pertinent to the development of urban systems at higher spatial scales (Dieleman and Faludi, 1998). The fact that the impact of physical distance is likely to be much smaller for other types of flow such as information and money (Camagni and Salone, 1993) than for human corporeal interaction also motivated our decision to concentrate specifically on human corporeal interaction. One may expect the urban systems constituted by flows of people to vary substantially from those constituted by other types of flow.

Although previous studies mainly focus on work-related aspects, we argue that non-work-related mobility flows should also be examined. Since spatial entities, such as FURs, encompass multiple functions and the interactions between them are also driven by non-work-related aspects, one may obtain very partial knowledge if one focuses exclusively on work-related aspects. The current analysis has therefore been conducted separately for business, holiday and leisure flows.

The remainder of this paper is organised as follows. The theoretical framework for analysing spatial interaction is discussed in section 2. An overview of the data, the delimitation of the FURs employed and the data operationalisation are presented in section 3. The configurations of the French and German urban systems are described in section 4. The paper concludes with a discussion of the issues raised.

2. Dimensions of Interaction

The functional concept 'urban system' was introduced by Berry (1964). Pred (1977, p. 13) uses the corresponding concept 'system of cities', which he defines as "a national or regional set of cities which are interdependent". In theory, the configurations of urban systems can be placed on a continuum ranging from fully monocentric to fully polycentric systems (Batten, 1995). The former term refers to a situation when only one (or a few nodes) dominate(s) the system as a result of the concentration of the specialised functions. The fully polycentric system refers to the situation where the system lacks truly dominant nodes because specialised opportunities are distributed across urban areas (Kloosterman and Musterd, 2001). Although the concepts of monocentrism and polycentrism are often used at the metropolitan level, they are applied to describe the configurations of urban systems at the inter-metropolitan level in this study.

Flows in urban systems can be characterised by three S-dimensions (Dijst and Cortie, 1988). The first dimension is the *strength* of the interactions. According to Simmons (1986, p. 26), the level of integration in a system is a function of "the sum of all flows of some types within the system as a whole". When nodes are intensively related to one another, changes, new ideas, innovations and so forth can be transmitted from one node to the other more readily (Simmons, 1986; Smith, 2003). The presence of strong interactions between such elements as cities and regions is thus an important building-block of urban systems (Bourne and Simmons, 1978; Friedmann, 1978). From the work of Sinclair (1983) and Smith and Timberlake (1995a), for example, the *symmetry* dimension can be distilled. The interactions between cities can range from completely asymmetrical (that is, a unidirectional relationship) to fully symmetrical (that is, a bidirectional relationship with the flows in both directions being equally large). Asymmetrical interactions are characteristic of interactions in a fully monocentric system; the most important city (or cities) containing the most and the more specialised functions receive flows from less important cities, but do not send flows in return. In this case, the asymmetrical interaction indicates a dependent relationship between the two nodes. In contrast, the symmetrical interactions are characteristic of interactions in a fully polycentric system, where nodes function as complements to other nodes to which they are connected. The third dimension refers to the *structure* of the system. The structures of urban systems can range from a hierarchical structure, as in a fully monocentric system, to a non-hierarchical structure, as in a fully polycentric system. Non-hierarchical structures are characterised by the "diffusion of impulses through the system in horizontal, diagonal, reciprocal and other directions, rather than downward in a hierarchical manner" (Sinclair, 1983, p. 108).

Related to the structure dimension is the *dominance* of a node in an urban system. The dominant node concept has received considerable attention across many research traditions: centrality and prestige in social network analysis (for example, Freeman, 1979; Wasserman and Faust, 1994) and urban primacy in geographical studies (Sassen, 1995; Smith and Timberlake, 1995b). Depending on the nature of the interaction, the dominance of a node could be determined by taking or not taking the directionality of flows into account. Mitchell (1969) states that, in employer–employee or patron–client relationships, the influence of one person on another will differ according to the direction of the interaction. However, for reciprocal personal relationships such as friendship, the direction of the flows is not important. This relevance of the directionality of flows also applies to interactions in urban systems, which are in essence relationships between actors. If the flows considered are determined by the use of facilities, products or services tied to geographical locations at nodes of arrival, it is important to take the directionality of flows into account. Incoming flows (aimed at a specific location) are then more relevant in defining a city's dominance. Our reasoning here is similar to that of Alderson and Beckfield (2004) who see incoming flows as an indication of the prestige of a city; the dominant nodes contain opportunities that are sought by other cities in the wider system. However, for certain types of flow the importance of node and the directionality of flow are less clear and need not necessarily be taken into account. Examples of such flows are journeys undertaken to visit family and friends or journeys that can be undertaken for both acquiring and offering products and/or services.

In this paper, the three S-dimensions and the level of dominancy are used to determine various forms of interactions among FURs in the national urban systems (see Figure 1). Figure 1 shows various ideal types of urban system for four-node networks, ranging from a fully monocentric network, characterised by fully asymmetrical interactions between the dominant and non-dominant nodes, to a fully polycentric network, in which there is no dominance but rather equally strong symmetrical relations between nodes. We draw a distinction between directional and non-directional urban systems on the basis of the relevance of the directionality of flows. In principle, each urban node belongs to both types of system.

As can be seen from Figure 1, the networks are to some extent snapshots on a continuum. In theory, in the fully monocentric system, all interaction involves one node, which is the absolute heart or hub of the network (A1/B1). For the directional networks (when only incoming interaction is considered), the degree of symmetry increases from left to right along the horizontal axis, while the extent of hierarchy or the central function of the dominant node becomes gradually weaker along the vertical axis. First, interaction between non-dominant nodes becomes possible, although the magnitude of these flows is much smaller than flows in which the dominant node is involved (Network A2). Then, flows between the dominant and non-dominant nodes become more symmetrical (Network A3) and the difference in the strength of flow between dominant and non-dominant nodes and among non-dominant nodes becomes less pronounced (Network A4), indicating that the hierarchical structure is weakened. Finally, all flows are equally large and fully symmetrical, resulting in a 'flat' network, without any node being more important than the others (Network A5). This is referred to as a fully polycentric network. Four non-directional networks equivalent to A1, A3, A4 and A5 can be distinguished; they are numbered B1–B4 and differ from one another in terms of the level of hierarchy in the system. It is anticipated that, in real-life situations, networks tend to fall between the extremes of the fully monocentric and fully polycentric networks; few, if any, urban systems will look like A1/B1 or A5/B4.

It should be remembered that the networks in Figure 1 are ideal types, built on very specific premises: there are only four nodes; the nodes are either dominant (or central) or they are not; and flows on links are either fully asymmetrical or fully symmetrical. Of course, in real-world situations many variations on these premises are possible. We did not address these in our enumeration of archetypal networks, because we felt they would distract attention from our key interest—the three S-dimensions. In section 3, we describe a set of five indicators for operationalising and distinguishing between archetypal networks. The reason for which we propose a set of indicators rather than one measure is that, to the best of our knowledge, no single indicator capturing the three S-dimensions is available.

3. Research Design

3.1 Data

In the current study, data on long-distance personal travel have been employed for examining the pattern of interaction between FURs in the French and German urban systems. These data were chosen because they enable

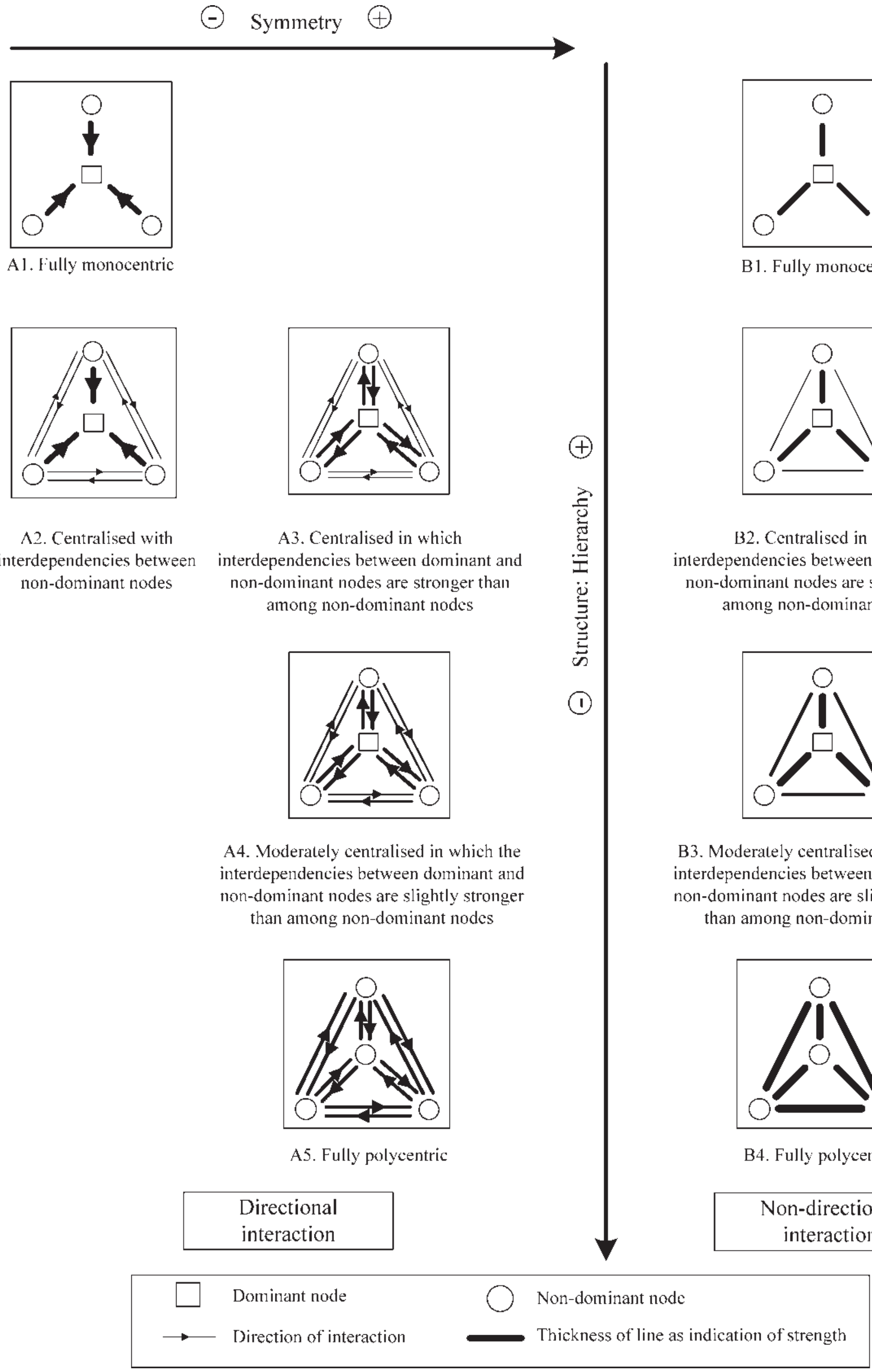


Figure 1. Archetypal networks: directional and non-directional interaction.

us to concentrate on human corporeal interaction over long distances, which is increasingly important for the development of urban systems at the intermetropolitan level (Frandberg and Vilhelmson, 2003; Urry, 2003). This information is rather difficult to extract from general travel surveys in which information for a single day or at most a week is collected, because most travellers do not undertake long-distance trips on a daily or weekly basis (Dateline Consortium, 2002). Furthermore, the data cover various types of travel and thereby various kinds of corporeal interaction. Rather than limiting ourselves to firm-related business journeys, we have also been able to investigate holiday travel and journeys undertaken for leisure purposes. One may argue that leisure is inherently a short-distance phenomenon. As the work of John Urry (2003) and others shows, the increase in leisure travel over longer distances is the most important reason for the increasing importance of long-distance travel in general. A drawback of the data is that only flows of persons can be considered; the exchange of information, money and goods remains unexamined because we do not have access to the appropriate datasets of these types of flow. Although we acknowledge that other types of flow such as information, money and especially goods should be considered for acquiring a full view of the urban systems in France and Germany, data on flows of persons also offer important insights in these systems and suffice for illustrating the properties of the theoretical and methodological framework proposed here.

DATELINE (Design and Application of a Travel Survey for European Long-distance Trips Based on an International Network of Expertise) is concerned with European long-distance travel mobility. 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 12 consecutive months. In this survey, a long-distance journey was defined as a journey that includes a destination more than 100 kilometres away (as the crow flies); only journeys originating from the respondent's home base are analysed in this study. For each journey, a main destination is identified and it is this information that has been used for the current study. Although the 100 km threshold used in the survey enables us to focus specifically on interaction at the intermetropolitan level, one might argue that this definition could lead to an underestimation of the interaction between contiguous areas. This effect is expected, however, to be relatively small in this study, because the physical distances between the centres of FURs in most cases tend to exceed 100 km.

The national samples of individuals were randomly selected at the NUTS-1 level.[1] Respondents who both do and do not undertake long-distance journeys are recorded in the database. The total net response for the 16 countries was around 80 000 individuals (over the age of 15) and 101 000 long-distance journeys in total. The data contain some household, personal and travel information including journey purpose, transport mode and geographical information on the origins and destinations of long-distance journeys at the NUTS-3 level. Weight factors are provided in the DATELINE data to make the data representative of the total population for each spatial unit (NUTS-1 level) with respect to the gross distribution of gender, age, household size, employment status and number of cars available per household (Dateline Consortium, 2003b) and these weights have been applied in this study. Nevertheless, it should be kept in mind that, as previous research has shown, long-distance travel tends to be more prevalent among people with more resources, particularly those on higher incomes, those with higher levels of education attainment and men (Limtanakool *et al.*, 2006). This is because long-distance travel incurs considerable time and costs.

Three journey purposes are analysed in this study—namely, business, holiday and leisure. By definition, a business journey is a journey made for business purposes. Professional travel by truck drivers, pilots and the like is excluded. Journeys made for holiday purposes constitute the second category. The third journey purpose is leisure and comprises journeys made for general recreational activities, culture, sports and shopping. In general, holiday journeys are less frequent and involve longer travel distances and time spent at destinations than leisure journeys. For these reasons, we believe that the holiday and leisure journeys are qualitatively different from one another. We therefore decided to analyse them separately. Commuting was excluded from this analysis, because the number of observations per spatial unit was too low for the analysis results to be meaningful. For the present study, around 4847 long-distance domestic journeys between FURs were selected for France ($n = 2637$) and Germany ($n = 2210$). International journeys were not analysed because in most cases they account for less than 20 per cent of the total long-distance journeys per journey purpose in both countries. The small number of international journeys and the dispersion of international long-distance destinations result in small numbers of observations per origin–destination (OD) pair, which are frequently too low for meaningful analysis.

Delimitation of FURs. Although geographical information on the origin and destination of long-distance journeys was recorded in the DATELINE data at the NUTS-3 level, it is preferable to use spatial units that are functionally interrelated in economic terms, because these can be compared with one another more easily (Cheshire and Hay, 1989). For this reason, we employ the FURs concept, which refers to contiguous NUTS-3 regions grouped together according to their functional orientations. This delimitation is inspired by the second report of the GEMACA project (IAURIF, 2002), in which FURs were considered the most desirable spatial units for comparative socioeconomic analysis across European metropolitan areas.

Central to our method of delimitation is the identification of significant employment concentrations and the areas over which these economic centres extend their influence. Ideally, economically functional interdependencies between areas should be derived from relational data such as daily commuter flows. However, as we do not have access to comparable short-distance commuting data for our study areas (that is, for Germany or France), we have defined FURs on the basis of five variables measured at NUTS-3 level: the ratio of jobs to the size of the active population; the number of jobs; job density; the number of inhabitants; population density. The data used to define the FURs were obtained from the 1997 regional statistics collected by EUROSTAT. On the basis of these criteria, six FURs were identified and defined in France and eight in Germany (Figure 2).

Spatial interaction indices. Five indices were devised to measure the three S-dimensions of spatial interaction: the entropy index (EI); dominance index (DII_i and DIT_i); node symmetry index (NSI_i); relative strength index (RSI_{ij}) and the link symmetry index (LSI_{ij}). The descriptions and formulas of these spatial interaction indices together with their relationships with the three dimensions are presented in Table 1.

These indices can be categorised in three groups according to their measurement level—namely, network, node and link. The EI is an index at the network level. It measures the extent to which the total interaction is distributed evenly across all links in the network. The EI can therefore be considered a measure of the structure dimension, with a value of one indicating a fully polycentric network.

The NSI_i and the dominance index (DII_i and DIT_i) are measured at the node level. NSI_i is related to the dimensions of symmetry. It measures the difference between the incoming and outgoing interactions for every node i. A positive net interaction suggests that the node is primarily a receiver; a negative value suggests that it is more important as a sender. When the NSI_i values for all nodes in the network are examined, the index also provides information about the structure dimension. If all nodes have a value of zero, the network can be classified as fully polycentric (A5/B4 in Figure 1).

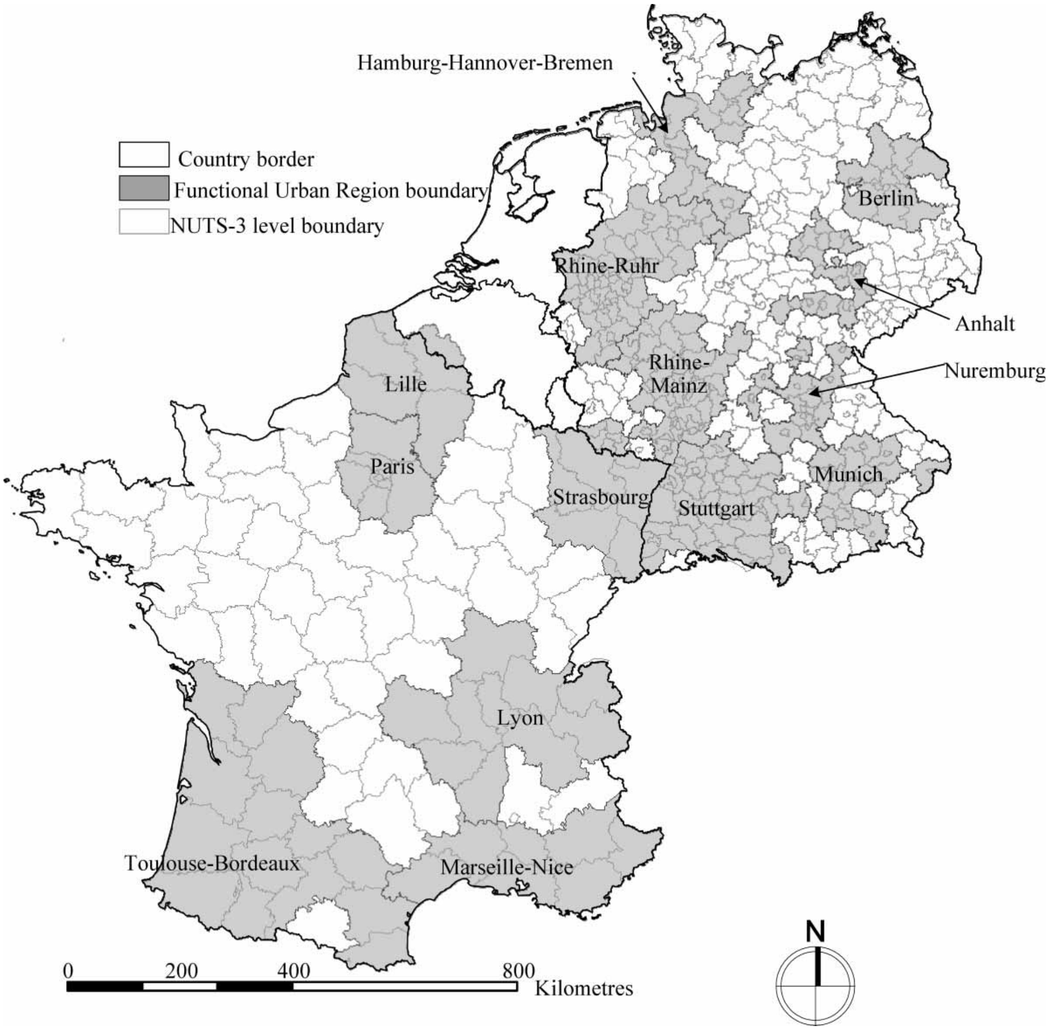


Figure 2. Functional urban regions (FURs) in France and Germany.

The dominance index indicates the degree of involvement of a node in the network. Depending on the type of flow, the direction of flows is considered or not in the calculation of this index. If direction is not taken into account, incoming and outgoing flows are summed for each node, resulting in what further is called the non-directional interaction. In this study, the directionality of flow is taken into account in the identification of dominant nodes in the holiday and leisure networks, but not for business flows. In addition to the theoretical issue discussed previously, in our case we decided not to take the direction of flow into account for business journeys, because the data employed did not allow a detailed distinction to be drawn between the types of activities pursued during business journeys. Consequently, the importance of the node and the directionality of flows would be less clear-cut for business flows.

The non-directional dominance index (DIT_i) is defined as the ratio between the sum of the interactions associated with node i and the average size of the interactions associated with other nodes in the network. If the directionality is taken into account, the

Table 1. Spatial interaction indices: description, formula and their relations with dimensions of spatial interaction

	Entropy (EI)	Dominance (DIT_i and DII_i)	Relative strength (RSI_{ij})	Node symmetry (NSI_i)	Link symmetry (LSI_{ij})
Equation	$EI = -\sum_{i=1}^{L} \frac{(Z_l)Ln(Z_l)}{Ln(L)}$ for $z = 0$ holds that $(z)\mathrm{Ln}(z) = 0$	$DIT_i = \frac{T_i}{\left(\sum_{j=1}^{J} T_j/J\right)}$ $DII_i = \frac{I_i}{\left(\sum_{j=1}^{J} I_j/J\right)}$	$RSL_{ij} = \frac{t_{ij}}{\sum_{i=1}^{I}\sum_{j=1}^{J} t_{ij}}$	$NSI_{ij} = \frac{\sum I_i - \sum O_i}{\sum I_i + \sum O_i}$	$LSI_{ij} = -\left[\frac{(f_{ij})Ln(f_{ij}) + (f_{ji})Ln(f_{ji})}{Ln(2)}\right]$
Minimum/maximum value	$0 \leq EI \leq 1$	$0 \leq DII_i$ and $DIT_i < \infty$	$0 \leq RSI_{ij} \leq 1$	$-1 \leq NSI_i \leq 1$	$0 \leq LSI_{ij} \leq 1$
Relations between dimension of spatial interaction and indices					
Strength	–	0: a node is not involved in the network $\rightarrow\infty$: a node dominating the network as every interaction in the network is associated with this node	0: a link does not exist 1: highest strength of a link	–	–
Symmetry	–	–	–	−1: a node is asymmetrical by having a maximum deficit of net flow 0: a node is fully symmetrical in terms of its net flow 1: a node is asymmetrical by having a maximum surplus of net flow	0: a link is fully asymmetrical: an interaction only exists in one direction 1: a link is fully symmetrical: there is two-way interaction and flows in each direction are equally large

(*Table continued*)

Table 1. Continued

	Entropy (EI)	Dominance (DIT_i and DII_i)	Relative strength (RSI_{ij})	Node symmetry (NSI_i)	Link symmetry (LSI_{ij})
Structure	0: all interaction is concentrated on one link in the network 1: no hierarchical structure (when every link in the network has equal intensity of flow)	A network does not have a hierarchical structure when every node in the network is associated with equally large flows	A network does not have a hierarchical structure when every link in the network is equally strong	A network does not have a hierarchical structure when every node in the network has $NSI_i = 0$	A network does not have a hierarchical structure when every link has $LSI_{ij} = 1$

Key:
l Link in the network ($l = 1, 2, 3, \ldots, L$).
Z_l Proportion of journeys on link l in relation to the total number of journeys in the network.
I_i, I_j The number of inward journeys to nodes i and j.
T_i,T_j The total number of journeys associated with nodes i and j.
t_{ij} The number of journeys from node i to j.
O_i The number of outward journeys from node i.
f_{ij} The proportion of journeys on the link from node i to node j in relation to the total number of journeys between nodes i and j.
f_{ji} The proportion of journeys on the link from node j to node i in relation to the total number of journeys between nodes i and j.
i, j $i = 1, 2, 3, \ldots, I$; $j = 1, 2, 3, \ldots, J$; for $i \neq j$.

focus is only on incoming interactions The directional dominance index (DII_i) is defined as the ratio of the interactions received by node i to the average size of the interactions received by other nodes in the network. It can be said that the network is dominated by node(s) with a high score for the dominance index. For both indices, we consider a node with a dominance index value that exceeds the value of one to be a dominant node, because its role is more important than the average role of other nodes in the network. The network structure could also be examined by scrutinising differences in dominance index values among nodes in the network: large differences would imply the presence of a hierarchical structure.

Furthermore, the RSI_{ij} and LSI_{ij} are two indices measured at the link level between nodes i and j. The former indicator is related to the strength dimension and RSI_{ij} measures the proportion of interaction on a given link between two nodes relative to the total interaction in the network. The RSI_{ij} values for all links in the network thus sum to unity. As with the dominance index, the directionality is taken into account for holiday and leisure flows, but not for business flows. LSI_{ij} measures per link the extent to which the one-way interaction equals the interaction in the other direction; a value of one shows that the amount of interaction from node i to j is exactly the same as from j to i. In this study, link symmetry is analysed not only at the link level, but also at the node level. LSI_{ij} values on links attached to node i are averaged to give the node-level indicator LSI_i. Two versions of the average link symmetry are employed in this study. The first is the unweighted mean of LSI_{ij} values: the LSI_{ij} values of all links connected to node i are summed and divided by the number of links. The disadvantage of this method of calculating the mean is that all links are deemed equally important in determining the LSI_i value, regardless of their role in the network. A weighted average is therefore also computed of link symmetry, in which the strength of a link is utilised as a weight factor. That is, the extent to which LSI_{ij} values are taken into account is proportional to the weight attached to it. If the weighted average LSI_{ij} value is higher than the non-weighted average, this suggests that the stronger links attached to the node in question are more symmetrical than the weaker links. Each index gives information about the structure in the network when values on all links or nodes are examined together: large differences in index values would imply the presence of a hierarchical structure (see Table 1).

Characterisation of interaction patterns. The characterisation of spatial interaction patterns was carried out as follows. We started with the *EI* to describe the evenness of the distribution of interaction across all the links in the network. We then proceeded with the results of the other indices to make qualitative judgements about the state of the complete network. Our approach comprised two stages. First, we identified a set of dominant nodes with the help of the dominance index. As described earlier, nodes whose dominance index value amounts to one or more qualify as dominant nodes. The directional dominance index using incoming interaction (DII_i) is employed for holiday and leisure journeys, and the non-directional dominance index for business journeys (DIT_i).

After examining the dominance index, we concentrated on the node symmetry value(s) for the dominant node(s) to gain further insight into the role of nodes in the network. A positive NSI_i value corresponds with a surplus in net flow and a negative value a deficit in net flow; a node is considered balanced if its NSI_i value is close to zero. Because node symmetry is the result of the exchanges between a node and other nodes in the network, we can understand the value of the NSI_i for a node by scrutinising the relative strength values of the links connected to it. In the discussion of the results for RSI_{ij}, we have paid most attention to the results for the links involving at least one dominant node.

We then assessed the average level of symmetry of the links connected to a node (LSI_i), concentrating particularly on the dominant node(s). If the weighted average link symmetry value for a dominant node is closer to one than to zero, this suggests that the node in question holds reciprocal relationships with other nodes in the network based on complementarity. In that case, the position in the network would resemble that of the dominant node in situation A3/ A4 in Figure 1. If, on the other hand, the (weighted) average LSI_i value for a dominant node is close to zero, situation A1/A2 in Figure 1 is suggested. The (weighted) average LSI_i value thus provides important insights into the structure in the system.

Collectively, from the results for *EI* and all other indices (that for the most part are) presented per dominant node, we are able to describe the state of the complete network. The reader should remember that the archetypal networks in Figure 1 are ideal types, comprising only a few nodes only one of which is dominant. In reality, however, patterns are more complex, messy and ambiguous. While this complexity makes mapping real-world networks neatly onto the ideal-type states in Figure 1 difficult, we can describe the essential properties of real-world networks using the indicators presented to identify the various ideal-type networks. Thus, the networks in Figure 1 should be seen as heuristic devices guiding the empirical analysis rather than as mutually exclusive categories to be used for classifying complete networks. Real-world networks, especially larger ones, are most likely to contain several of the ideal-type states; these may, or may not, partially overlap. The archetypal states in Figure 1 are nevertheless useful in facilitating the understanding of real-world networks, as the application of the framework to characterise interaction patterns in France and Germany makes clear.

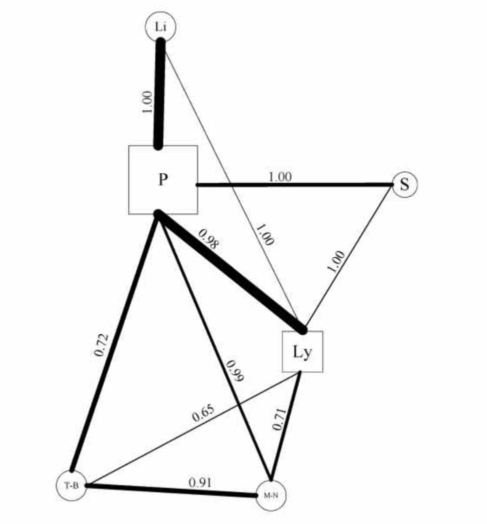
4. Application of the Framework

In this section, the proposed theoretical framework is illustrated by empirical data. The pattern of spatial interaction between FURs as constituted by long-distance personal travel is characterised for two national networks, France and Germany. Besides the fact that France and Germany are important European countries, they have been chosen because of their contrasting urban constellations. France has a centralised national urban system and is known for its strong urban hierarchy and the primacy of Paris. Germany, however, is known for its decentralised system, with large cities spatially distributed over the country. Carrying out the analysis for these two countries enables us to assess whether our approach yields acceptable results in both sets of circumstances. In this study, the French urban networks comprise six FURs and the German eight (Figure 2).

4.1 France

Business journeys. In France, long-distance business journeys between FURs account for 33 per cent of all domestic long-distance journeys. The interaction is fairly evenly distributed across links in this network, as indicated by the *EI* value of 0.81. Some key results for the other indices are presented in Figure 3 (diagram 3.1) which shows all the nodes in the network and a selection of the links between them. The area representing a node is proportional to the value of the dominance index: the larger it is, the more dominant is the node. Note also that dominant nodes are represented by squares and non-dominant nodes by circles. To ensure that the stylised map remains readable, only links connected to dominant nodes or those with the sum of RSI_{ij} exceeding the value of 0.04 are depicted in the figure. Although this threshold was chosen arbitrarily, it allows us to focus on links that have an important role in the network. The thickness of the lines is indicative of their relative strength. For ease of presentation, RSI_{ij} values calculated for both directions on a link have been aggregated into one value. The numbers printed along the links represent their LSI_{ij} values.

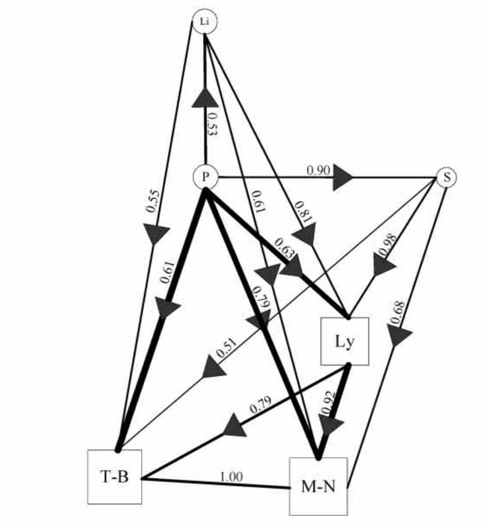
Diagram 3.1 shows clearly that Paris dominates the business travel network with its DIT_i value of 2.83. This value implies that the size of the interaction associated with Paris is 2.83 times larger than that associated



	Interaction indices			
	Dominance[a]	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Paris	2.83	0.03	0.78	0.97
Lyon	1.04	0.20	0.72	0.92
Lille	0.78	0.05	0.79	1.00
Marseille-Nice	0.74	-0.35	0.72	0.86
Toulouse-Bordeaux	0.73	-0.07	0.71	0.79
Strasbourg	0.41	0.00	0.83	0.99

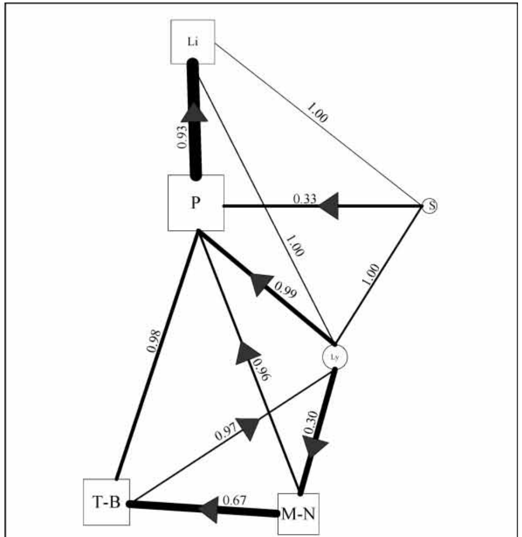
[a]For total travel used for business travel the dominance index is calculated over all trips; for leisure and holiday travel the index is calculated over incoming journeys only (see section 3.1 for more explanation)

1 Business travel



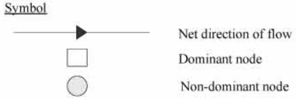
	Interaction indices			
	Dominance	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Marseille-Nice	2.01	0.40	0.67	0.88
Toulouse-Bordeaux	1.80	0.55	0.58	0.80
Lyon	1.37	0.09	0.69	0.86
Paris	0.51	-0.63	0.58	0.67
Lille	0.45	-0.15	0.58	0.67
Strasbourg	0.31	-0.23	0.68	0.77

2 Holiday travel



	Interaction indices			
	Dominance	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Paris	1.98	-0.03	0.70	0.94
Toulouse-Bordeaux	1.34	0.41	0.66	0.87
Lille	1.22	0.28	0.73	0.94
Marseille-Nice	1.07	-0.05	0.39	0.69
Lyon	0.55	-0.38	0.71	0.61
Strasbourg	0.17	-0.44	0.47	0.50

3 Leisure travel



Remarks
- The number printed along each link represents the LSI_{ij} value
- Net direction of flow is not indicated if link is perfectly symmetrical (i.e. $LSI_{ij} = 1.0$)
- Area of a node is a function of dominance index value
- Thickness of the line is a function of the summed up RSI_{ij} values
- Only links connected to dominant node or those with summed up $RSI_{ij} > 0.04$ are depicted in the figures

Abbreviation
Li = Lille
Ly = Lyon
M-N = Marseille-Nice
P = Paris
S = Strasbourg
T-B = Toulouse-Bordeaux

Figure 3. Relationships among the main functional urban regions in France, by type of long-distance travel.

with the average of the other nodes in the network. Although Lyon also qualifies as a dominant node, it is clearly overshadowed by Paris, suggesting that this network has a strongly hierarchical structure. The examination of NSI_i values suggests that Paris is well-balanced in terms of net interactions, since its NSI_i value approaches zero. Other nodes in the network can also be considered relatively well-balanced, with the exception of Marseille-Nice, which is more of a sender than a receiver. The deficit in net flow of Marseille-Nice can be explained by the fact that it sends a large number of business journeys to the nearby nodes of Toulouse-Bordeaux ($RSI_{ij} = 0.08$) and Lyon ($RSI_{ij} = 0.06$). The fact that Marseille-Nice sends more business journeys to these two nodes than to Paris indicates the existence of a sub-system in southern France embedded within the larger national system dominated by Paris. Detecting a clear hierarchy among the three nodes within this sub-system is difficult.

Furthermore, with respect to the strength of interaction, we find that the interaction between Paris and Lyon is very strong; this link accounts for around a quarter of the total interaction within the network. However, Paris and Lyon have different roles in the network: while Paris interacts with various nodes in the network, Lyon has only weak relations with nodes other than Paris. A similar situation can be observed for Lille. Although not shown in the diagram, we find that Lille is not as isolated as diagram 3.1 may suggest, however, because Lille also interacts with the Brussels-Antwerp area in Belgium.

Looking at the network as a whole, we see that, except for the link between Marseille-Nice and Toulouse-Bordeaux, the interaction between non-dominant nodes is only weakly developed. With respect to link symmetry, we see that links attached to Paris tend to be relatively symmetrical. This finding is also borne out by the average LSI_{ij} value of 0.78 for Paris. Links involving Lyon tend to be less symmetrical.

On the basis of these results, we can say that the structure of the network for long-distance business travel exhibits a clear hierarchy with Paris functioning as the overall dominant node. Although only weakly developed, interaction can be observed between all non-dominant nodes and this finding implies that the overall network can best be compared with B2 (Figure 1). However, given that Lyon acts as a secondary dominant node and interrelations between the southern nodes are more balanced, the network also exhibits elements of network B3. Nevertheless, for the network as a whole, the strong level of hierarchy and centralisation around Paris are the most defining characteristics.

Holiday journeys. Holiday journeys account for 55 per cent of all domestic long-distance journeys in France. The distribution of flow across links in this network is more balanced than that found in the business travel network ($EI = 0.89$). As explained earlier, the directional interaction based on incoming flows is more appropriate for computing the dominance index for holiday journeys. However, to enhance the readability of the diagram, the two arrows between each FUR pair (as in Figure 1) are collapsed here into a single arrow indicating the net direction of flow. Strikingly, Figure 3 (diagram 3.2) shows that Paris does not constitute a dominant node ($DII_i = 0.51$). The results demonstrate that Marseille-Nice, Toulouse-Bordeaux and Lyon are the most important destinations for domestic holiday journeys in France. This finding is related to the concentration of specialised functions and natural amenities attracting holiday journeys to the southern parts of the country. The fact that the DII_i values among these three nodes do not differ much, particularly those between Marseille-Nice and Toulouse-Bordeaux, suggests that this network is not dominated by one, but rather by a group of nodes; a situation that is clearly different from the primacy of Paris in the business travel network.

The NSI_i values also reveal the prominent role of these three nodes as destinations for holiday journeys, because they are the only nodes with a positive NSI_i value in the network. Toulouse-Bordeaux gains the largest surplus in terms of net flow, followed by Marseille-Nice, while the gain for Lyon is rather small. All non-dominant nodes function as senders. This is particularly true for Paris, as indicated by its substantial deficit in net flow ($NSI_i = -0.63$). The distinction between the dominant nodes functioning as receivers and non-dominant nodes functioning as senders again makes it clear that it is the natural amenities and tourism industry in southern France that are important in structuring the holiday travel network. At the same time, the interactions reproduce the tourism industry in that part of the country.

To the extent that the attractiveness of a node is reflected by the magnitude of incoming interaction, Marseille-Nice and Toulouse-Bordeaux equal one another, given that the LSI_{ij} value for the link between them amounts to one. On the basis of the holiday journeys sent from non-dominant nodes, it can be said that the three dominant nodes are equally attractive, because the shares of interaction sent from the same origin to these destinations are almost identical.

Overall, the level of link symmetry is lower for long-distance holiday travel than for business travel (diagrams 3.1 and 3.2). Diagram 3.2 also shows that link asymmetries exhibit a clear pattern; most of the arrowheads point towards the three FURs in southern France, thus confirming their role as centres in the network. The (weighted) LSI_i values for Toulouse-Bordeaux, Lyon and Marseille suggest that the network is weakly centralised around these dominant nodes. Note, however, that the unweighted and weighted averages for these three nodes differ from one another considerably. This difference results mainly from the highly symmetrical interaction between Lyon and Marseille-Nice and Toulouse-Bordeaux and Marseille-Nice.

On the basis of these findings, this network can be described as having a polycentric structure in which the interaction is clearly biased towards three centres in the south. This network is a combination of archetypes A2 and A3 (Figure 1) with the difference that it has not one, but three dominant nodes. The central roles of Marseille-Nice, Toulouse-Bordeaux and Lyon are in line with expectations, given the concentration of natural amenities and tourism services in these areas. The relatively low level of link symmetry shows that there is a clear distinction between a node functioning as a sender, like Paris, and as a receiver.

Leisure journeys. Travelling for leisure constitutes 13 per cent of all long-distance domestic journeys between FURs in France. The distribution of flow across links in this network is rather uneven ($EI = 0.77$). As with the holiday journeys, the directional interaction based on incoming interactions is used for leisure journeys and only the net direction of flow is indicated in Figure 3 (diagram 3.3). The dominance index values for incoming interaction show that Paris is the most important destination for leisure journeys, followed after a considerable gap by Toulouse-Bordeaux, Lille and Marseille-Nice (diagram 3.3). The fact that four nodes emerge as dominant nodes is to some extent the result of Lyon and Strasbourg in particular playing a limited part in the network. If they had a larger role, Marseille-Nice would not be considered dominant. The position of Paris as the most important node is, however, unambiguous. In fact, the FURs could be grouped into three classes: the most important node, Paris; the secondary nodes, Lille, Toulouse-Bordeaux and Marseille-Nice; the tertiary nodes, Lyon and Strasbourg. In terms of node symmetry, we see that Paris and Marseille-Nice are approximately balanced in terms of net interaction, while Lille and Toulouse-Bordeaux function primarily as receivers. However, the Lille FUR is not very influential in the wider network considered here, because in fact Paris is Lille's only important partner. Diagram 3.3 suggests that the large surplus in net interaction for Toulouse-Bordeaux is the combined result of the many journeys it receives from Marseille-Nice and the small number of journeys it sends to other nodes in the network.

Although it cannot be discerned from diagram 3.3, we find that, on seven unidirectional links, no interaction could be observed in the data; that is to say, for instance, that no person included in the database travelled for leisure purposes from Lille to Toulouse-Bordeaux. This lack of interaction is one of the reasons underlying the relatively low value of *EI* reported earlier. It is worth noting that no interaction was observed in either direction between three pairs of nodes: Lille and Toulouse-Bordeaux; Lille and Marseille-Nice; Strasbourg and Toulouse-Bordeaux. These results reflect the relevance of the geographical proximity of nodes given that, typically, interaction between distant nodes located in the north and the south of the country is lacking.

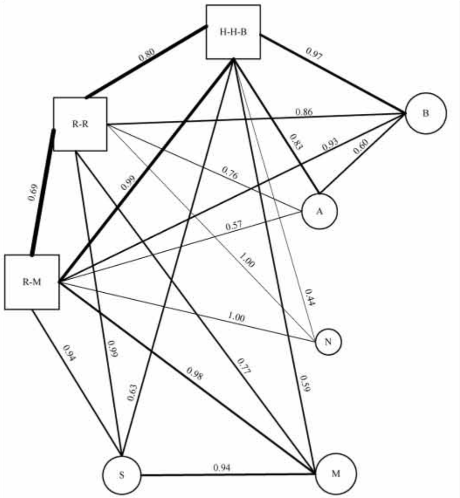
The weighted average link symmetry values show values close to the maximum value of one for the three most important nodes in the network: Paris, Lille and Toulouse-Bordeaux.[2] This proximity to the maximum value suggests that archetype A3 (Figure 1) typifies the network as a whole, although it deviates from that ideal type in at least two respects. First, rather than a binary distinction between dominant and non-dominant nodes, the nodes in the network can be grouped into three classes: more dominant (Paris); less dominant (Lille, Toulouse-Bordeaux and Marseille-Nice); and non-dominant (Lyon and Strasbourg). Secondly, no journeys are observed for a considerable number of (unidirectional) links. The fact that no interactions between distant nodes are more frequently observed for leisure than for business or holiday travel suggests that leisure journeys are more localised than business or holiday journeys. Travellers are probably able to find a leisure destination fulfilling their needs in smaller geographical areas than they can for holiday and business journeys. In addition, because they trade travel time and activity duration against each other (Dijst and Vidakovic, 2000; Schwanen and Dijst, 2002) and leisure activities tend to be of shorter duration than business and certainly holiday journeys, travellers may be reluctant to travel long distances for these activities.

Summary. The results have shown that network constellations vary considerably across journey purposes. With respect to the business travel network, we see that Lyon is a secondary dominant node after Paris. In overall terms, this network is clearly hierarchical and fairly centralised, meaning that it is most similar to network B2. For holiday travel, we see a polycentric network falling between A2 and A3, in which three nodes are equally dominant: Toulouse-Bordeaux, Marseille-Nice, and Lyon, all functioning as important destinations. When compared with the business network, this network is less hierarchical and closer to the fully polycentric state A5 (Figure 1): there are more dominant nodes and differences in relative strength across links are smaller. Finally, the leisure network resembles network A3 in many respects. Here Paris clearly dominates the network, as was the case for the business network. In contrast with that network, we observe here a group of three secondary dominant nodes that does not include Lyon. Another important characteristic is that no interaction was observed for many north–south links, including the various links between secondary dominant nodes.

The position of FURs thus varies considerably between the networks. As expected, Paris plays an important part in every journey purpose either as a sender or origin of a journey, which reflects (among other things) the concentration of population in this area. Paris dominates, however, in only two of the three networks; it attracts relatively few domestic holiday journeys. Lyon is dominant when it comes to holiday travel, and also for business, but not for leisure. On the other hand, the position of Strasbourg is fairly constant in all three networks. It plays a minor part in all of them since it is mainly oriented towards Paris. Strasbourg is therefore the most isolated node of all the FURs considered here.

4.2 Germany

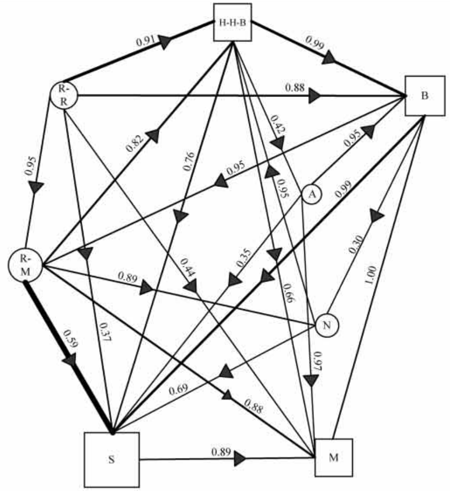
Business journeys. Long-distance business journeys account for 58 per cent of all



	Interaction indices			
	Dominance[a]	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Rhine-Mainz	1.60	-0.22	0.76	0.83
Hamburg-Hannover-Bremen	1.55	-0.43	0.66	0.75
Rhine-Rhur	1.50	0.32	0.73	0.83
Munich	0.92	0.49	0.62	0.87
Berlin	0.89	-0.25	0.70	0.81
Stuttgart	0.76	0.07	0.66	0.89
Anhalt	0.66	0.21	0.58	0.75
Nurnberg	0.32	0.24	0.68	0.81

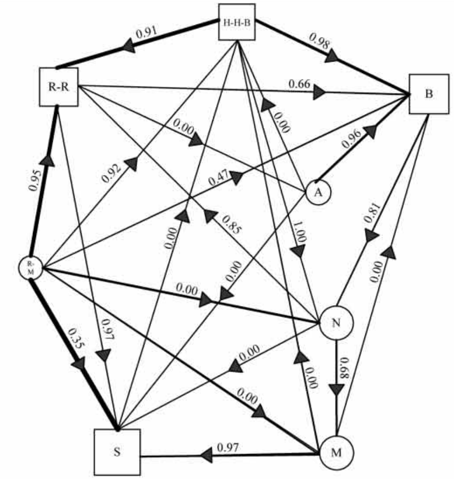
[a]For total travel used for business travel the dominance index is calculated over all trips; for leisure and holiday travel the index is calculated over incoming journeys only (see section 3.1 for more explanation)

1 Business travel



	Interaction indices			
	Dominance	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Stuttgart	2.46	0.50	0.58	0.81
Berlin	1.30	0.01	0.76	0.89
Munich	1.19	0.43	0.69	0.88
Hamburg-Hannover-Bremen	1.16	-0.04	0.69	0.81
Rhine-Mainz	0.91	-0.35	0.69	0.74
Rhine-Rhur	0.60	-0.43	0.68	0.74
Nurnberg	0.43	0.15	0.56	0.78
Anhalt	0.32	-0.17	0.52	0.76

2 Holiday travel



	Interaction indices			
	Dominance	Node symmetry	Link symmetry (average)	Link symmetry (weighted average)
Stuttgart	1.69	0.60	0.33	0.74
Berlin	1.32	0.26	0.55	0.89
Rhine-Rhur	1.19	-0.05	0.55	0.72
Hamburg-Hannover-Bremen	1.09	0.00	0.48	0.94
Nurnberg	0.91	0.18	0.42	0.63
Munich	0.91	0.28	0.21	0.59
Anhalt	0.53	-0.13	0.12	0.42
Rhine-Mainz	0.49	-0.67	0.34	0.37

3 Leisure travel

Symbol

- Net direction of flow
- Dominant node
- Non-dominant node

Remarks
- The number printed along each link represents the LSI_{ij} value
- Net direction of flow is not indicated if link is perfectly symmetrical (i.e. $LSI_{ij} = 1.0$)
- Area of a node is a function of dominance index value
- Thickness of the line is a function of the summed up RSI_{ij} values
- Only links connected to dominant node or those with summed up $RSI_{ij} > 0.04$ are depicted in the figures

Abbreviation

A = Anhalt
B = Berlin
H-H-B = Hamburg-Hannover-Bremen
M = Munich
N = Nurnberg
R-M = Rhine-Mainz
R-R = Rhine-Rhur
S = Stuttgart

Figure 4. Relationships among the main functional urban regions in Germany, by type of long-distance travel.

long-distance domestic journeys between FURs in Germany. The total interaction is evenly distributed across the links in the network, as indicated by the *EI* value of 0.91. The Rhine-Mainz, Hamburg-Hannover-Bremen and Rhine-Ruhr areas are dominant in this network (Figure 4, diagram 4.1). The finding that the variation of the DIT_i values of these three nodes is only 0.1 suggests that the three nodes are equally important. Given that the dominance index values are lower and the number of nodes identified as dominant is larger than for France, the German business network can be considered less hierarchical than its French counterpart. When the symmetry of the nodes is examined, we see that they have different roles in the network. The Rhine-Ruhr area is the only dominant node that functions as a receiver ($NSI_i = 0.32$); the Hamburg-HannoverBremen and Rhine-Mainz areas and also Berlin have a deficit in net flow.

Diagram 4.1 shows that the Rhine-Mainz and Hamburg-HannoverBremen areas both send a large number of business journeys to the Rhine-Ruhr area, but the magnitude of flow they receive in return is rather small (the RSI_{ij} values from the Rhine-Ruhr to the Rhine-Mainz and Hamburg-HannoverBremen regions are both 0.02). There are few strong relationships among the non-dominant nodes. The only exceptions are the relations between Berlin and Anhalt and between Stuttgart and Munich. Both links are between nodes in geographical proximity to one another, which suggests that network patterns are partly shaped by distance in physical space. The results for link symmetry reveal that the weighted average level of link symmetry in this network is not very high; the values for the weighted average link symmetry per node are all below 0.9 and lower than for the business journey network in France.

Overall, the network can be classified as a variant of ideal type B3 (Figure 1), with multiple dominant nodes: the Rhine-Mainz, Hamburg-HannoverBremen and Rhine-Ruhr FURs. Geographically, a difference in the concentration of interaction can be observed between the north-west and the rest of the country: in the north-western part, flows are strong while in the south and east the interaction is weaker. However, the relations between Munich and Stuttgart and between Berlin and Anhalt suggest that there are subsystems in the south and east embedded in the national network. Nuremberg seems to form no part of these systems and to be only weakly linked to the dominant nodes, which suggests that it is relatively isolated within this network.

Holiday journeys. Holiday journeys account for 30 per cent of all long-distance domestic journeys between FURs in Germany. The distribution of interaction across links is similar to that found in the business network ($EI = 0.90$). The DII_i values indicate that Stuttgart is the main attractor in this network, followed after a considerable gap by Berlin, Munich and Hamburg-Hannover-Bremen (diagram 4.2). On the basis of the dominance index values, the German FURs could be classified in three groups: the primary dominant node of Stuttgart; the secondary nodes of Berlin, Munich, Hamburg-HannoverBremen and the Rhine-Mainz area; and the non-dominant nodes of the Rhine-Ruhr area, Nuremberg and Anhalt. The NSI_i values show that Stuttgart and Munich acquire a large net flow ($NSI_i = 0.50$ and 0.43 respectively). The substantial surplus in net interaction for Stuttgart can be understood by examining the strength of links connected to it. While Stuttgart only sends a small fraction of holiday journeys to other nodes, it receives a large amount of holiday journeys from various destinations, particularly from Rhine-Mainz ($RSI_{ij} = 0.12$), which constitutes the strongest unidirectional link in the complete network.

With respect to the relations between the dominant nodes, we see that the interaction between Berlin and Hamburg-HannoverBremen is strongest ($RSI_{ij} = 0.07$), followed by that between Berlin and Stuttgart ($RSI_{ij} = 0.06$). The unweighted and weighted LSI_i values of 0.58 and 0.81 respectively for Stuttgart suggest that the stronger links associated with Stuttgart are more symmetrical than the weaker links.

On the basis of these results, we can say that the overall network for long-distance domestic holiday travel in Germany falls somewhere between A2 and A3. The degree of centralisation is smaller than in A2, because the interaction between Stuttgart and other nodes is not as asymmetrical as in that archetype. In addition, there is a range of second-tier dominant nodes and for two of them—Berlin and Munich—interaction with other nodes is more symmetrical than for Stuttgart. Compared with the business network, interaction is less concentrated in the north-western part of Germany. Again, the roles in the national network performed by Anhalt and Nuremberg are relatively small.

Leisure journeys. This journey purpose accounts for 12 per cent of all long-distance domestic journeys between FURs in Germany, the lowest share. The interaction is less evenly distributed across links in this network than in the case of business or holiday journeys ($EI = 0.84$). An important reason for this difference lies in the fact that no interactions were observed for about a quarter of all possible unidirectional links in the network. The finding that the network for leisure journeys is less integrated than are the business and holiday travel networks is in line with the findings for France and may result from the same factors: individuals are able to fulfil their needs at shorter distances from their home base and/or more are unwilling to travel longer distances for leisure purposes.

Examining the dominance index values in diagram 4.3, we see that Stuttgart is the most important destination in this network ($DII_i = 1.70$), followed by Berlin ($DII_i = 1.32$), the Rhine-Ruhr area ($DII_i = 1.19$) and Hamburg-Hannover-Bremen ($DII_i = 1.09$). The presence of four dominant nodes suggests that the network structure is less hierarchical than that for long-distance holiday journeys; the extent of the hierarchy is more or less comparable with that in the business network. The node symmetry values make it clear that Stuttgart has a substantial surplus in net interaction, followed at some distance by Berlin, while the Rhine-Mainz FUR functions as a major sender in the network.

With regard to the strength of the links, we have not found any interactions between the two most dominant nodes in this network: Stuttgart and Berlin. These two nodes differ in terms of the nodes from which they receive journeys. While Berlin receives journeys from various sources in similar shares, Stuttgart mainly receives flow from Rhine-Mainz ($RSI_{ij} = 0.12$). Berlin's influence in the network would seem to be less concentrated and more evenly distributed than Stuttgart's. The role of Rhine-Mainz as a major sender is illustrated by the fact that the amount of interaction it generates accounts for 33 per cent of all domestic leisure journeys in Germany. Interestingly, Nuremberg also plays a part in this network since it attracts a substantial number of journeys from Rhine-Mainz and Berlin.

As diagram 4.3 shows, the unweighted LSI_i values in the leisure network are very low; that is because of the large number of links for which no journeys were observed. It is therefore more appropriate to look at the weighted average LSI_{ij} values. The value for Stuttgart suggests that its pattern of interaction with other nodes tends to be moderately centralised, lying midway between the dominant nodes in A2 and A3 (Figure 1). A similar picture emerges for Rhine-Ruhr. Berlin and Hamburg-HannoverBremen, however, seem to be closer to A3.

In short, it can be concluded that this network is less integrated than are the other networks and that Stuttgart is the most dominant node, followed by Berlin, the Rhine-Ruhr area and Hamburg-HannoverBremen. All in all, this network can be considered a mixture of A2 and A4 networks, because interaction on the links involving dominant nodes is not fully symmetrical and the level of hierarchy is less than in the network for holiday journeys. Another important difference from the German networks previously discussed is that a considerable number of links between dominant and non-dominant nodes has not been observed.

Summary. Our findings for Germany show again that the pattern of flows between FURs and dominant nodes varies according to journey purpose. The structure of the German business network is clearly less hierarchical than its French counterpart, with Rhine-Ruhr, Rhine-Mainz and Hamburg-HannoverBremen having comparable roles as dominant nodes. The results reveal a different pattern of interaction for the holiday network. This is dominated by Stuttgart; a large difference in the DII_i values between Stuttgart and the other nodes suggests the presence of a clearer hierarchical structure in the network. Two of the dominant nodes in the business network, the Rhine-Ruhr and Rhine-Mainz areas, are found to have an important function as a sender in the holiday network; this function is related to the concentration of the population in these areas. For leisure journeys, the pattern of interaction is less integrated than for the other networks, given that no journeys were observed for a significant share of the links. Although this network is still dominated by Stuttgart, the network of leisure journeys is less hierarchical than that for holidays, because of the lower dominance index value for the primary dominant node, Stuttgart, and the smaller difference in values from the runner-up, Berlin. The analysis also makes it clear that not all nodes are involved to the same extent in each of the networks. Anhalt, and to a lesser degree Nuremberg, have only limited roles. Anhalt's isolated position is to some extent comparable to that of Strasbourg in France.

5. Conclusion

The concept of polycentrism has been used extensively in the literature on urban development to describe urban system configurations in advanced economies. In this paper, we have proposed the three S-dimensions of interaction (that is, the strength of interaction, the symmetry of interaction and the structure of the network) and a set of indicators to characterise the system configurations. To assess the general utility of our approach, we employed data from the European long-distance travel mobility database (Dateline Consortium, 2003a) to examine the pattern of interaction between FURs in the French and German urban systems. The analysis was carried out separately for long-distance business, holiday and leisure travel.

The empirical analysis confirms the existence of various configurations of urban systems and the complex nature of interaction patterns, even in networks with only a limited number of urban nodes. On the basis of our findings, the proposed framework yields satisfactory results in characterising the two national urban systems (that is, France and Germany) with contrasting constellations. Concerning business travel, the French urban system has a fairly strong hierarchical structure with Paris as a primary dominant node, while the German urban system is less hierarchical because it is led by a group of nodes (that is, the Rhine-Ruhr, Rhine-Mainz and Hamburg-HannoverBremen areas). In both countries, we see that the regions with the greatest concentrations of population hold a dominant position in the network of business journeys.

With respect to holiday travel, the French network has a polycentric structure with the three nodes located in the southern part of the country (Marseille-Nice, Toulouse-Bordeaux, Lyon) as the major attractors. The network is slightly more hierarchical for the German case. Although several nodes in the German holiday network are identified as dominant, Stuttgart stands out among these. In both countries, we observe a north–south movement of flows that is related to the concentration of natural amenities and tourism facilities in the southern urban areas in both countries. Furthermore, the leisure journeys are observed to have the least integrated networks. In France, Paris is the only node that interacts with all the other nodes in the network. Although the structure of the German system is somewhat less hierarchical than its French counterpart, the system is dominated by Stuttgart. In both countries, the strength of interaction is related to geographical proximity.

All in all, the results show that characterising the urban systems through three important dimensions of spatial interaction makes the complexities of networks easier to comprehend. Furthermore, the framework is applicable at various geographical scales. It has been employed here to investigate flows at the intermetropolitan level, but it could also be used to analyse interaction patterns between settlements within FURs, neighbourhoods within settlements, blocks within neighbourhoods and so forth.

While the framework offers useful insights into configurations of urban systems, there are at least four issues that merit attention in future research. First, on the basis of our results, one important direction for further work is the combination of the interaction approach put forward here and approaches based on place attributes. This direction is important given that the empirical analysis in this paper suggests a close relationship between the interaction between nodes and the characteristics of a node, such as the number of related opportunities or attractions. The proposed framework does not address the characteristics of nodes directly and cannot be used to reveal the relationship between, for instance, the configuration of urban systems and the economic prosperity of urban systems/urban nodes. However, the possibility of classifying and identifying the configurations of urban systems offered by the proposed framework is a precondition for obtaining insights into this relationship. More specifically, the proposed interaction indices can be used as independent variables in the multivariate statistic analysis to examine the extent to which the economic prosperity of urban nodes (GDP per capita, for example) can be explained by their role and participation within the wider network of exchanges. The dominance index, for instance, is a direct measure of the importance of a node in the network in relation to other nodes and can easily be utilised for this purpose.

Secondly, the proposed framework can be applied to other types of flow data: flows of daily commuters, goods, money, information and so forth. Since we observe a considerable variation in the configurations of urban systems across journey purposes and countries based on human corporeal interaction, different patterns of urban systems are likely to emerge if other types of flow such as information and money are analysed. Nevertheless, depending on the type of flow considered, some modifications of the interaction indices may be necessary, especially whether or not the directionality of flows needs to be taken into account.

Thirdly, to the extent that different configurations of urban systems evolve over time, the application of this approach can be used to monitor the developments of urban systems in, for instance, the dimensions of symmetry and the strength of interaction at multiple time points; these would yield insights into the dynamics of urban systems. Finally, we believe that an important challenge lies ahead in the application of the framework to networks with a large number of nodes. These and other challenges will be taken up in the next steps of this research endeavour.

Notes

1. The Nomenclature of 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 NUTS-1 level, as defined in terms of the number of inhabitants, is between 3 and 7 million inhabitants, whereas the NUTS-3 level is between 150 000 and 800 000 inhabitants.
2. Because the LSI_{ij} for links for which no interaction has been observed has been set at zero, the unweighted LSI_i values are considerably lower than the weighted values. Because this network contains many links without any interaction, we decided to give more emphasis to the weighted LSI_i when characterising the network, taking into account the fact that the network is not fully connected.

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