CITIES IN THE REGIONALIZED WORLD OF MULTINATIONAL FIRM NETWORKS

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ABSTRACT

The capacity of cities to operate in global networks of firms is usually measured based on the degree of centrality of their position within networks of multinational firms across the globe. However, we assume that regional groups of cities that interact more intensively with each other are more relevant to define central positions. This paper aims to identify these regions and assess their relative influence on the globalization of cities through multinational firm networks. A global database has been generated for the network of 1 million direct and indirect ownership links between the 800,000 subsidiaries of the top 3,000 multinational firms of the world, which are located within 1,205 metropolitan areas. One finding that emerges from this research is that globalization occurs mostly through intra-continental linkages but is also facilitated by strong intra-national and even intra-urban sub-networks. Local intra-urban network complexity is shown to influence the process of global integration. Distance still influences globalization, but not with the same intensity within different parts of the world. A "spin glass clustering" procedure is used to define the different classes. These classes underline the regional structure of the complex network of global cities, which are organized into "small worlds" that correspond partially to continents but exhibit interesting cross-continent patterns. Only a few cities link these groupings together. The multi-scale centrality of cities is discussed based on the concepts of geographic and economic integration within multinational firm networks.

KEYWORDS

MULTINATIONAL FIRMS, CITIES, WORLD REGIONS, NETWORKS, GRAVITATION MODEL, GRAPH THEORY, CLUSTERING

INTRODUCTION

Multinational corporations invest preferentially in cities, interacting with urban economic resources by integrating these plants into the strategic planning of the entire firm (Rozenblat, Pumain, 1993; Castells, 1996; Taylor, 2001; Rozenblat, 2010; Wall & van der Knaap, 2011). Approximately 80% of multinational firms' plants are located inside urban regions (Rozenblat, Pumain, 1993; Scott, 2001; Rozenblat, 2011). However, it is much more difficult to measure globalization in urban regions than on a national scale due to the lack of available data (Rozenblat, Pumain, 2007; Wall & van der Knaap, 2011). International studies of foreign direct investment between states still dominate the literature (Rugman, 1980; Rugman et al., 2012; Dunning, 1992, 1998; Wall et al., 2011; Dezzani, Johansen, 2012).

Interstate analyses of global integration processes are nevertheless relevant, even in urban studies, because the interdependencies between cities do not develop within territories that are homogenous and open as argued by Ohmae (1990) or Friedman (2005). Instead, multinational firms transversally weave a system of territories, producing their own properties, rules and regulations (Yeung, 1998; Dunning, 2002; Ghemawat, 2007; Rugman et al., 2012). Thus, the national level must be taken into account, but the continental level also seems to serve an important purpose due to the creation of free-trade zones, which tends to reinforce continental systems (Ohmae, 1996; Rugman, 2001; Dicken, 2003; Yeung, 2002; Rozenblat, 2004; Pomfret, 2007; Rugman et al. 2012). Nevertheless, continental regions as roughly defined are perhaps not the appropriate geographic level at which to detect cohesion, and other geographic associations may matter more to the organization of global economic links. From a national to a worldwide scale, firms are concentrated in sub-national regions (Scott, 2001) that are linked within national systems, sometimes with cross-border effects; with other national systems inside continental zones; and in an intercontinental framework.

In this multi-scale geographic system, intense economic specialization creates groups of cities that are more and more interrelated despite long distances (a tendency that is reinforced by national policies related to "poles of excellence" or "poles of competitiveness"). The most often quoted example of this phenomenon remains that of financial specialization, that has generated a "global city" linking New York, London and Tokyo (Sassen, 1991). The other cities of the world are supposedly connected to this central system and are seen as being linked in a simple hierarchy that is erroneously based on unique rankings of "world cities" (Friedmann, 1986; Taylor, 2001; Brown et al., 2010).

Given the importance of the regionalization of the world, we instead assume that the "world cities" are not generating a system that is entirely independent of territorial boundaries or other geographical barriers and preferential relationships. Some regional systems have progressively created dense groups of interrelated cities. Our hypothesis is that firms take advantage of these "host regions" supported by very integrated urban systems, in which some world cities in each region serve as "bridges" to the global system. Moreover, we wish to determine to what extent national factors are still relevant and examine the influence of geographical scales ranging from the international to the local.

In this paper, we propose to identify the roles of these regions in the global integration of cities by empirically evaluating a large sample of networks of multinational firms. We focus on the network properties of these regions, comparing their capacity to integrate city networks. The international organization of networks of multinational firms will first be discussed in relation to the global integration of cities (section 1); the hypotheses will be tested using a global database of networks of multinational firms built between cities that have been defined comparatively (section 2). The distribution of these networks will be outlined for different geographical scales (section 3). We will test the combined effect of distance/city size using a gravitation model for the various continents (section 4). However, this gravitation model does not fit as expected, which suggests that other factors also matter in the process by which multinational firms develop intercity linkages. Thus, we will employ clustering analysis, defining the regions in which the cities are more intensively interlinked, and we will validate these regions using a new gravitation model (section 5). This process yields more satisfying results, with the organization of these regional classes of cities characterized in more detail. We will discuss these classes and the factors that have generated them.

1. REGIONALIZATION OF CITIES BY MULTINATIONAL FIRMS

The regionalization of cities by multinational firms is analyzed in three different fields:

- The world city networks are studied by geographers and sociologists;
- The regionalized world is studied by political sociologists and, using clustering techniques, by geographers and physicists;
- The determinants of firm internationalization are studied in business science and economics.

This multi-dimensional approach makes it possible to explain the mutual relationships between cities and firms (1.1). Cities and firms integrate mutually in a regionalized world (1.2) due to specific integration factors (1.3).

1.1 Cities' systems and multinational firm networks

Cities and business networks constitute a "duality" in which the latter now have a greater potential to structure the former (Neal, 2008). In return, businesses locate their headquarters and plants near the highly differentiated resources and markets offered by urban territories. The "space of flows" and the "space of places" (Castells, 1996) are closely connected in the structure and dynamics of cities, thus creating "*systems within systems of cities*" (Berry, 1964; Pred, 1977; Pumain, 1997, 2006). Global economic networks reinforce these city systems. In setting up their subsidiaries and production units and in generating internal and external exchange networks, multinational corporations position each territory and each city within a complex system of interdependencies. Synergies develop in particular locations through *agglomeration economies* (Marshall, 1920; Ohlin, 1933; Hoover, 1937, 1948; Jacobs, 1969; Henderson, 1988; Camagni, 1999; Gordon, Mc Cann, 2000; Duranton & Puga, 2004; Ellison & Glaeser, 2007) and between different locations through *network economies* (Castells, 1996; Bathelt et al., 2004; Johansson, 2005; Kalrsson et al., 2005; Capello, 2009; Rozenblat, 2010). Bathelt et al. (2004) suggested that global interactions between cities are reinforced if the corresponding local networks are well developed, as empirically demonstrated by Rozenblat (2010). This dynamic within urban development may constitute part of the definition of the "world city".

Patrick Geddes proposed the first definition of "world cities" in 1915, describing them as the places in which global business is concentrated. The later definitions proposed by Peter Hall (1966) and Hymer (1972), like the "world cities hypothesis" by John Friedmann (1986), were consistent with this tradition, exploring some functions of central and peripheral cities in the world economy (e.g., as the locations for headquarters and stock exchanges). The first measures of these hierarchies were based on population, the locations of headquarters, world events and air traffic passengers (Cohen 1981; Meijer, 1993; Lyons & Salmon, 1995). However, as argued by Alderson and Beckfield (2004), power is not related to location alone: "*the power of world cities is inherently relational: cities do not have power in and of themselves; they have power to the extent that they function as command points and centers of planning and thus establish the framework in which other cities operate in the world economy*". (Alderson & Beckfield, 2004, p.812).

The definition of "global cities" presented by Saskia Sassen (1991) more specifically suggests that advanced production services (APS) spur on the process of globalization of cities by concentrating their power. This idea has been further developed by the Globalization and World Cities group (GaWC), led by Peter Taylor (2004, 2010). However, the approaches developed by the GaWC group, which analyze the construction of networks of APS firms between cities, can be strongly criticized because complete graphs are built between all locations of every corporate group, which introduces some structural bias into the network analysis (Neal, 2012).

Wall and van der Knaap (2009) identify “global cities” based on rankings for networks of financial firms (APS firms) and identify “world cities” with reference to all economic sectors of multinational firms. The former were studied by considering the ownership networks formed by the series of stakeholder/subsidiary links (a maximum of five) for the most successful global corporations in all activity sectors (Rozenblat, Pumain, 1993; 2007; Wall, 2009). Alderson and Beckfield (2004, 2010) also adopted this approach but include only one level of subsidiary. The subsidiary links make it possible to specify “power” cities, which feature a concentration of ownership links, and “prestige” on another hand, meaning attracting subsidiaries.

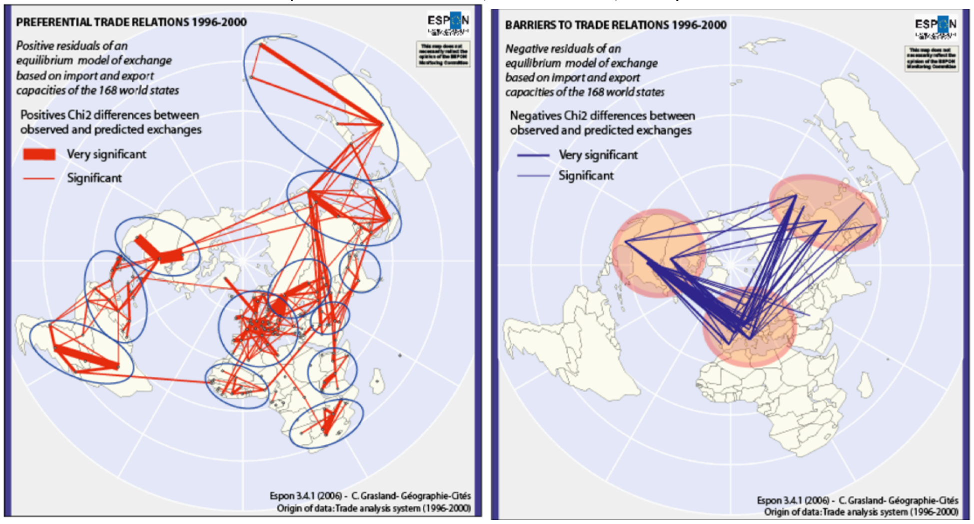
National institutions, political coordination and economic and innovation resources support the development of enterprises and cities (Sassen, 2007). The economic and social strength of cities and nations interact, forming a national system that is able to integrate cities into the globalization system. This particularly benefits home headquarters that receive investments, workers from across the nation and knowledge spillover (Rosenthal & Strange, 2001). However, although there is evidence of this strong relationship between cities and national economies, the direction of the relationship is uncertain, and a feedback loop may exist between city and state development (Polese, 2005). Locally, cities foster specialization and skill in specific sectors (Henderson, 1997, 2003) as well as diversity (Glaeser, 1994, 1998; Quigley, 1998; Duranton et Puga, 2002).The local complexity created by the location of many enterprises very close to each other in the same urban areas that are financially linked is rarely considered because of the lack of data available on this scale. On a global scale, this phenomenon concerns European and Asian cities in particular but very few American cities (Rozenblat, 2010).

The network approach to a firm’s ownership structure permits a skewed perspective on cities. It also makes it possible to identify processes that develop inside and between cities (Rozenblat, 2010) and in interaction with territorial organizations on various geographical scales that integrate different economic and social systems and institutional rules. The network approach also permits us to use graph theory to determine the highest-density areas on the graph for the regions of cities in the world system.

1.2 Regionalization of the world cities

The regionalization of the world is not simply an issue of cities. Since Myrdal (1957) and Wallerstein (1974), the regionalization of the world has been a topic of discussion (Chase-Dunn, Rubinson, 1977; Bornschier et al., 1978; Chase-Dunn, 1998; Sanderson, 2005; Dezzani, Johansen, 2012). Hymer suggested that the pattern of regionalization among the cities of the world is consistent with the hierarchy of countries (Hymer, 1972). Alderson and Beckfield (2004) confirmed this hypothesis, showing that the hierarchy of cities according to their multinational firm networks approximately matched their country’s status, whether central, semi-peripheral or peripheral, according to Bollen and Appold (1993). However, the researchers did not consider the geographical position of cities and countries, including the effects of geographic distance effects on these networks. Using a geographical approach, Grasland and Didelon (2008) regionalized the world according to barrier effects and regional preferences measured using the residuals of a gravitation model of international trade flows between 1996 and 2000 (Grasland, Didelon, 2008, p.73). The authors found 12 very well integrated regions within the world (with positive residuals), whereas the triad system appears less connected than expected (with negative residuals) (Fig.1).

Figure 1: Regional Preferences and Barrier effects in international trade 1996-2000
(Grasland & Didelon, ESPON 3.4.1, 2008)



Many techniques have been developed in the last 15 years by physicists as a means of classifying networks according to their local densities (Blatt *et al*., 1996; Girvan & Newman, 2001; Auber *et al*. 2003, Clauset *et al*., 2004; Guimera *et al*., 2004, 2007; Guimera & Amaral, 2005; Newman *et al*., 2006; Reichardt, Bornholdt, 2006; Traag, Bruggemann, 2008; Sathik *et al*., 2011, Newman, 2011). These researchers applied their techniques within numerous fields, from biology to social networks. In particular, Guimera et al. (2005) used a clustering algorithm for airplane traffic flows that revealed regionalization patterns that were greatly consistent with those of continents. Vittali and Battiston (2011) studied the stakeholder/subsidiary networks for multinational firms in European regions. They did not directly employ a clustering method for these networks but demonstrated the *Small World* properties of networks inside countries. They indicated that a pair of nodes' networks will decrease based on distance but that this change will vary according to the length of the path between the stakeholders and the subsidiaries. Thus, all of these studies demonstrate the relevance of the network approach and underline distance and country membership as factors that determine the organization of spatial networks for multinational firms.

1.3 Determinants of multinational firm networks' locations

The determinants of the locations of multinational firm networks have been continually studied in the business literature (for recent reviews, see Wall et al., 2011; Rugman et al., 2012). There are two primary general approaches: the micro-business and macro-economic approaches (Dunning, 1998).

At the micro-level of corporate strategy, business networks develop where local or regional clusters integrate the longest-range networks with different specific urban factors (Porter, 1996). According to Doz *et al.* (2001), our perception of systems becomes a global perspective on the world, including technology pockets, "intelligent markets" (i.e., specific markets) and identified capacities. However, firms that truly function in an entirely "global" manner and that perfectly consider the complementarity that should exist between their various plants are extremely rare (Rugman, 2001; Ghoshal & Bartlett, 1990, Bartlett & Ghoshal, 2002). Ghoshal and Bartlett (1990) proposed a model that distinguishes between four different types of international organization for firms based on two criteria: their responsiveness to local markets and their corporate integration:

- "Multi-domestic" firms are oriented toward markets but have low corporate integration.
- In contrast, "global" firms are very well integrated but do not consider different markets.
- "Transnational" firms excel in both areas.
- "International" firms are balanced in these two respects, but their performance in these areas is much weaker than that of the transnational firms. Such firms will either become "real"

"transnational" firms or maintain this incomplete pattern of production (as may sometimes occur based on the economic specialization of the firm; for instance, the British company Orange in the communication industry keeps its markets close to each other but encourages some homogenization without a strong global managerial orientation).

Transaction costs and benefits are crucial determinants of the character of such organizations (Coase, 1937; Williamson, 1985; Powell, 1990; Zayac and Olsen, 1993). Such costs and benefits can be influential whether they arise inside or outside the firm (Johanson and Vahne, 2011). At the intra-firm level, a firm's size, managerial structures, financial resources and R&D and marketing capabilities are the main factors that encourage internationalization (Rugman *et al.*, 2012). Venables (1999) has indicated the role of distance cost in the fragmentation of the world production. In addition, the density of the linkages in a local or national context influences industry performance and company strategy (Westney & Sakakibara, 1985; Ghoshal & Bartlett, 1990). In fact, value is created at the level of individual partners or institutional networks that influence the economics or governance of the firm and based on the properties and institutions of particular territories (Gereffi, 1996; Gereffi *et al.*, 2005; Mc Cann, Mudambi, 2005).

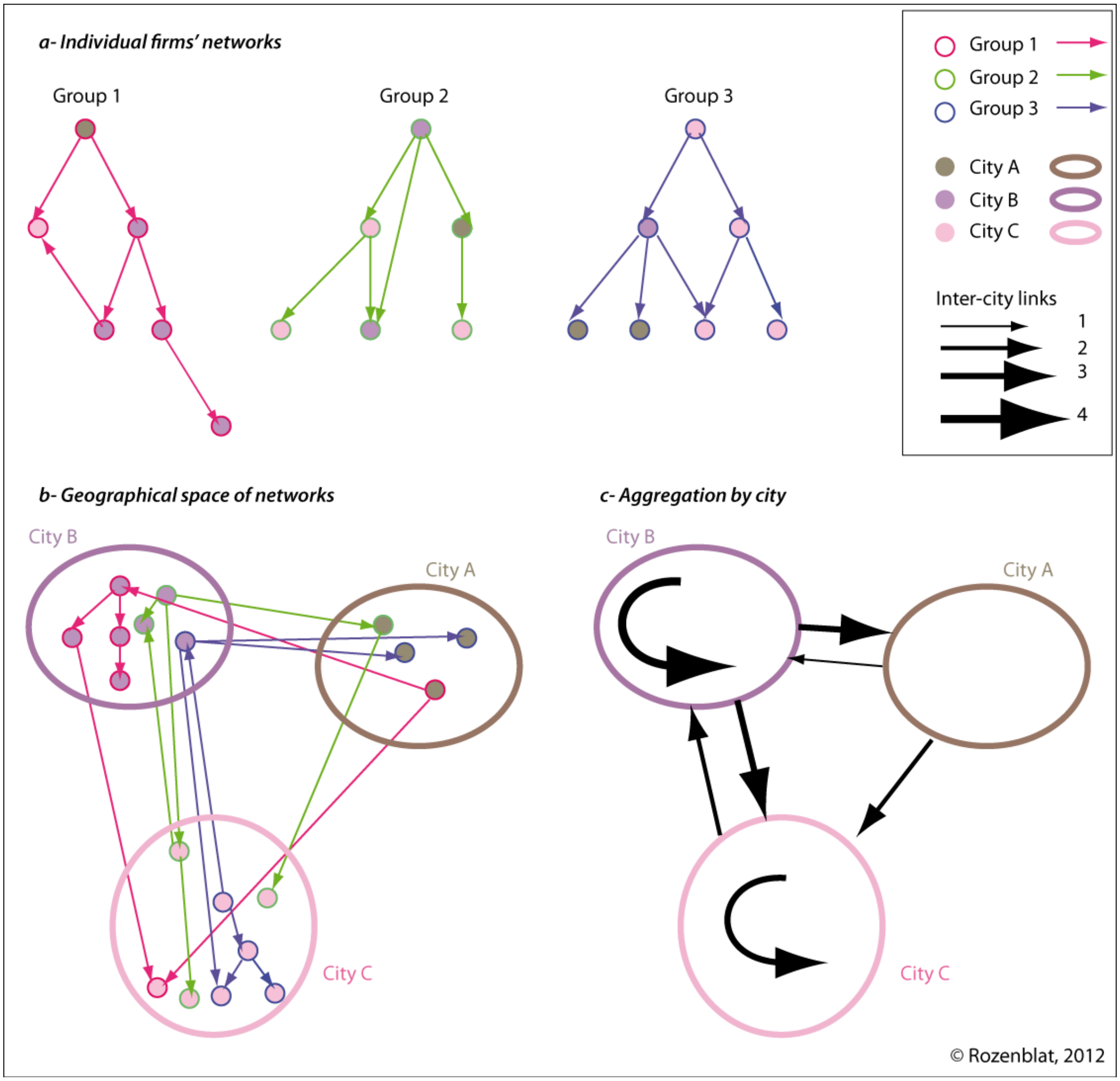
The macro-economic approaches more deeply emphasize the interaction between firm advantage and contextual advantage (Dunning, 1977, 1993; Rugman, 1981, 2012). Recently, Wall *et al.* (2011) developed a database that aggregated companies' ownership networks by country. Based on the "OLI paradigm" by Dunning (1977, 1993), Wall *et al.* (2011) empirically demonstrated that owner (O) advantages based on home-country-specific factors matter much more than location (L) advantages in determining the FDI flows between countries. These findings are consistent with the recent results of Rugman *et al.* (2012). In the home country, the degree of wealth (GDP), openness (relative international trade) and stock market capitalization greatly influence the strength of the FDI flows. In the host country, GDP also matters, but its influence is much smaller than that of distance. Wall et al. (2011) also demonstrate that physical distance has a negative effect, whereas cultural proximity (language and history) and difference in GDP have positive effects.

At the world city level, we consider how factors such as home city and host city advantages and distance are interconnected and how they influence the regionalization and hierarchies of cities. The dichotomy between cities and countries remains uncertain as we attempt to define the more relevant factors and the multi-scale organization of these networks connecting local places (cities), simultaneously including country and continent effects. The paper will present a regional analysis and graph analysis of the organization of these networks of multinational firms within the world city system. We will outline the evidence of this very complex system of cities, demonstrating how the continental approach can be outperformed by a clustering approach that is used to identify the more relevant regional sub-systems of the world.

2. DATA AND METHODOLOGY

To determine the positions of cities within such corporation networks, we first built a database of firm networks that includes all the direct and indirect subsidiaries of the top 3,000 worldwide company groups based on their turnover (Orbis, Bureau Van Dijk, 2010, Fig.2.a). According to their locations, we then aggregated these networks at the city level (with cities defined as large, functional urban areas) (Fig.2.b and Fig.2.c).

Figure 2: Building data: from individual networks of firms to city networks



The 3,000 largest groups directly or indirectly own 800,000 subsidiaries located all over the world that are connected by 1 million direct or indirect financial links. We used all links that constituted more than 5% ownership without any restrictions, unlike Wall and van der Knaap [2009, 2011], who stopped at 5 levels. We also retained the observations with missing values, knowing that links below 5% represent approximately 10% of the available information. We found a maximum of 34 levels of subsidiarity in a single network (that of Shell); in other cases, loops render the concept of "levels" irrelevant. All of the headquarters and subsidiaries are described by their activity sector (NACE), their turnover and number of employees when it is available, and their owners and subsidiaries. The information regarding the weight of the financial link is only available in 60% of cases. Thus, there are two options: one can consider the weight of the links (and delete the 40% for which this information is not available) (as is not specified but was surely performed in Benetton, 2007 and Vittali et al., 2011); or one can use every ownership link without the weight for each link. We chose the latter option, knowing that this option does not weight the individual ownership links. However, the intercity relationships are weighted: aggregating the ownership links for pairs of metropolitan areas, we consider the "number of links" between and within these areas. After they have been aggregated, the inter-city links are weighted based on the number of links from the owner cities to the subsidiary cities (Fig.2.b and 2.c).

To aggregate the data within comparable cities, each of the 800,000 individual firms was precisely located in a metropolitan areas (a 'functional urban area' in Europe according to the ESPON definition 2010, a MSA for the USA and Canada and the equivalent for the main cities across the globe based on Google Maps) (IGUL, 2010). The links were aggregated by metropolitan area using their origin and their destination. This process yielded a matrix linking 1205 metropolitan areas from all over the world. These areas contain more than 85% of the overall number of links of the database. Although we have a larger sample of subsidiaries, we obtain less numerous urban units than Alderson and Beckfield (2004, 2010), with 3,692 cities for 2000 and 6,308 cities for the period 1981-2007, because we considered the definition of urban areas to be much broader (in Europe, large urban areas are defined according to commuting flows; for instance, Wolfsburg is associated with Braunschweig and Vevey with Lausanne).

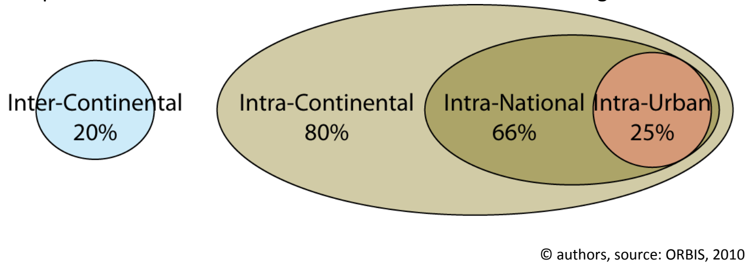
In addition to metropolitan areas, we might also consider free trade zones given that we would like to evaluate the regionalization of the world. However, because the free trade zones are very numerous and overlap, it was difficult to select precise levels for these zones. Thus, we preferred to begin with the continental zones in 6 regions as defined by the UN. This basic grouping method will be compared to the use of empirical clustering, as discussed later.

3- GEOGRAPHICAL SCALES OF NETWORKS UNDER GLOBALIZATION

The matrix of firm linkages between cities was first aggregated by continent. Although the 3,000 top companies are based equally often in Europe, North América, and Ásia, the position of European cities in this network is quite strong. More than the half of the total subsidiary links throughout the world, are located inside Europe, either inside one country or between two European countries. In addition, three quarters of the total ownership links are located in Europe alone or Europe and the rest of the world. These findings are easily explained by the high degree of fragmentation of Europe throughout history, which facilitated the industrial revolution, generating a high number of independent firms that had to develop agreements or merge, especially at the end of the 20th century under globalization. In addition, because of its national and industrial history, the European industrial system is much more complex than the Asiatic or the North American one (Dunning, 1992; Dicken, 2003). The urban system supports this complexity and, conversely, is very influenced by increases in economic network complexity (Mumford, 1961; Bairoch, 1985). This dynamic creates a very strong, diverse core that encourages network development and reinforces networks between the numerous European cities, from the smallest cities to the biggest metropolises.

Such complexity can also be found to some degree on the international scale, especially if we study FDI flows, considering monetary investment (Dickens, 1992, 2002; Mucchielli, 2008; CNUCED annual reports). However, FDI studies do not reflect the distribution of flows within particular countries or the local influence of the agglomeration economies that support and interact with these ownership networks (Fig. 3).

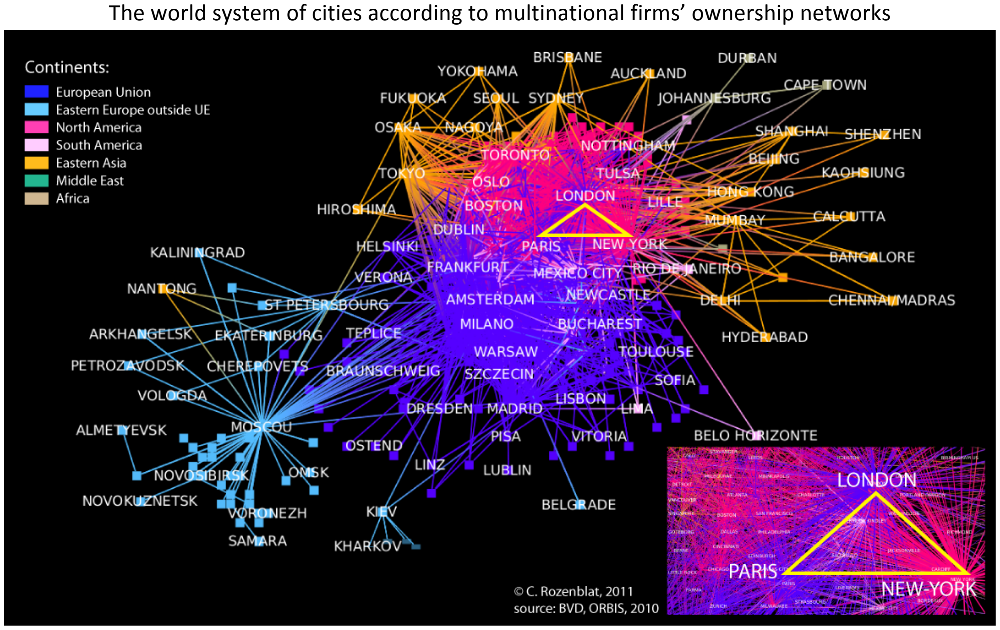
Figure 3
MULTINATIONAL FIRMS NETWORKS
Spatial links between owners and subsidiaries based on regional scale



This study is the first to evaluate these essential local links, confirming the agglomeration economies play a role on a global scale (Bathelt et al., 2004; Rozenblat, 2010). Moreover, globalization is strongly rooted in national systems, with two thirds of linkages remaining domestic. National structures indeed still matter, as the strength of a national economy makes it possible for businesses to expand abroad. This idea is consistent with the work of Sassen (2007) and Polese (2005), which argues that the development of cities is linked to their national systems.

When we remove the local links inside urban areas (250,000 links) and retain only the "external" links between cities, we obtain a matrix that crosses all of the cities that host the plants associated with the top 3,000 business groups in the world. This matrix includes 600,000 subsidiaries spread out over 1,205 metropolitan areas of the world. Some 100,000 enterprises included in the survey are located outside metropolitan areas, but they represent less than 15% of the total number of subsidiaries. The matrix can thus be represented by a graph that shows the intensity of the linkages between each pair of cities (based on the number of subsidiaries in one city controlled by headquarters in another city) (Fig. 4). The positions of the nodes in Figure 4 are calculated according to the intensity of the relationships between the nodes: city pairs that have more subsidiaries are closer than those that have fewer. Nevertheless, two cities can be positioned close together without any linkages if they are both significantly linked to the same third city.

Figure 4
The world system of cities according to multinational firms' ownership networks



The complex network of European cities, which in turn is linked with North American, South American and Asian cities, forms the main component of the graph. At the center are the major nodes, the core global locations for multinational firms that link all of the cities on their respective continents. Paris, London and New York dominate and are embedded in a dense network of cities of their continents. The global position of these large cities allows smaller cities with a more secondary position in the global network to access the entire world. Asia, in turn, is split into two parts; Japanese cities seem disconnected from Chinese, South East Asian and Australian cities. They do not play the same spatial role in globalization. A dramatically isolated group is formed around Moscow, which serves as a gateway between the other Russian cities and the rest of the world.

In terms of centrality in the network ("between centrality"), London is first, followed by Paris and New York. This result is consistent with those of Alderson & Beckfield (2010) and Wall & van der Knaap (2011) based on smaller samples. Paris only has one quarter of the number of foreign subsidiaries that London enjoys (5,000 versus 20,000). In particular, London hosts many American companies (35% vs. 23% for Paris) and Asian companies (6.6% vs. 3.6%), but interestingly, it also hosts many fewer European companies than the rest of the European cities. This finding confirms that London functions as a bridge for American companies in Europe but is much less integrated with the overall network of European firms than Paris (70% for Paris and 55% for London) (Rozenblat, Pumain, 1993, 2007). In addition, the capital cities of other European territories are also significant. This is particularly true in Central Europe, but it also holds for most of the world's developing countries. Uncertainty regarding the administration in these countries and a lack of information regarding them leads companies to settle first in these capital cities. This strategy allows firms to remain near key institutions such as banks, to build a local professional network and to acquire information that will ultimately allow them to identify a more appropriate production location. The capital of a nation thus bridges foreign countries and national cities. Only robustly federal countries such as Germany exhibit more balanced openness to foreign companies among their various cities. They thus have better visibility from abroad and are more rapidly integrated into the diffusion process for new knowledge and practices. Nevertheless, cities situated in centralized countries also can have good access to these networks due to the bridging role of capital cities in their internationalization.

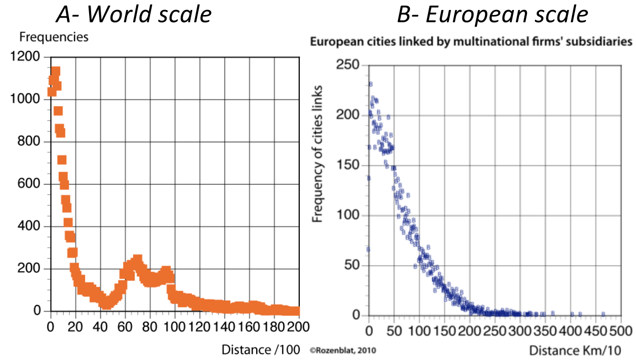
4. TEST OF GRAVITATION MODEL IN MULTINATIONAL FIRMS NETWORKS

In addition to these multi-level geographic patterns, distance still influences the relationships generated by multinational firm networks (Vitali, & Battiston, 2011; Wall et al., 2011). In fact, geographical distance drastically decreases these connections for the multinational firms of the world (fig. 5).

Figure 5

Number of couples of cities exchanging firms at certain distances

A- World scale *B- European scale*



The curve decreases based on the well-known distance cost (Ravenstein, 1885; Reilly, 1931; Wilson, 1980). Here, this cost reflects the cost of transporting goods, the difficulties of long range communication that persist even as new information technologies are developed, and the decreasing knowledge and increasing transaction costs associated with remote places. The world curve (fig. 5.A) decreases rapidly until 2,000 km (the threshold below which most linkages are between cities in neighboring countries) and then slows at 4000 km (the size of the continents). Oceans must be crossed at 5000 km; then, between 6000 km and 8000 km, intercontinental links appear. The intra-continental decrease in the curve is much clearer for the European scale (fig. 5.B). In essence, direct links appear to be limited by distance and barriers between continents.

4.1 Gravitation model on firms' ownership between cities

The effect of distance and size can be formalized using a gravitation model that assumes that the flow from place i to place j is proportional to the mass of i and j, and inversely proportional to the square of the distance between the two places (Ravenstein, 1885; Reilly, 1931; Isard, 1954; Ullman, 1954; Berry, 1971; Fotheringham & O'Kelly, 1989). The initial formula has been generalized with indexes for each independent variable, and the model is currently used in international economics to explain trade flows between countries (Bergstrand, 1985; Eichengreen & Irwin, 1998; Linder et al., 2008; Grasland & Didelon, 2008). The general formula that we wish to test is as follows:

$$F_{ij} = k \times \frac{M_i^{\alpha 1} M_j^{\alpha 2}}{D_{ij}^{\beta}}$$

where

F_{ij}: is the number of companies of the city j owned by companies of the city i

M_i, M_j: are the mass of the places i and j

α_1: is the multiplier parameter of owner city i

α_2: is the multiplier parameter of subsidiary city j

D_{ij}: is the distance from city i to city j (distance between cities i and j: here, we built different distances)

β: is the negative multiplier parameter of the distance, also called the friction of distance

Several independent variables were generated for these cities:

- Owner city: *i*
- Subsidiary city: *j*

Urban indicators for i (Owner cities: O_) and j (subsidiary cities S_):

- POPULATION_URB: City population based on the UN « Urban agglomerations » of the world (UN Demographic Yearbook 2008)
- INTRA_URB_LINKS: Based on our database, we summed the intra-urban links for each urban area;

National indicators attributed to i cities (Owner cities: O_) and j cities (subsidiary cities S_):

- NATIONAL_GDP: Each city was characterized based on its national GDP, a proxy for the national market that can be reached via each city (source: CNUCED 2011);
- NATIONAL_GDP/INHAB: Each city was characterized based on its national GDP per inhabitant, a proxy for the national wealth surrounding each city (source: CNUCED 2011);
- INTRA_NAT_LINKS: We summed the weighted intra-national links between cities (removing the intra-urban ones) and calculated the ratio of these intra-national links to the total links (also excluding the intra-urban ones);

Bilateral Indicators: D_{ij}

- DIST: the orthodromic distance between owner city I and subsidiary city j;
- R_GDP_INHAB: The ratio of the GDP per inhabitant of the country to which the owner city belongs divided by that of the country to which the subsidiary city belongs; this indicator measures the difference between the levels of wealth of the two countries in question;
- R_GDP: Ratio of GDP of the country to which the owner city belongs divided by that of the country to which the subsidiary city belongs; this indicator measures the difference between the market sizes of the two countries.

The model can be easily tested if we apply logarithms on both sides of the equation:

$$Log(F_{ij}) = Log(k) + \alpha_1 \times Log(P_i^1) + \alpha_{1'} \times Log(P_j^{1'}) + ... + \beta_1 Log(D_{ij}^1) + \beta_2 Log(D_{ij}^2) + ...$$

Using multiple linear regression, the model was applied to a global weighted matrix of ownership flows between the 1,205 cities excluding intra-urban linkages (which are used as the independent variable) and not taking into account the missing links (0 values). The model was tested on all of the global pairs of cities without missing values for the different parameters (24,769 pairs of cities) and for subsets of cities according to the continent to which they belong. Although this type of model has been criticized due to its logarithmic adjustment (Flowerdew & Aitkin, 1982; Burger et al., 2008; Linder et al., 2008), the model can be used to analyze the variance explained (R^2), whereas most other Logit models do not, indicating only the convergence of the model. Thus, we also used a binomial negative model to verify the latter while using a more appropriate model for these over-dispersed data (Long, 1997; Wall et al., 2011). Because the binomial negative model can include some qualitative variables, we used each pair of continents (O_CONTINENT * S_CONTINENT) as a bilateral variable.

4.2 Application of the gravitation model on the ownership flows between cities by continent

Tables were used to summarize the different gravitation models tested for the total sample or the weighted ownership links between cities and by continent using multiple regression analysis based on the log-linear model (Appendices: Tab. I).

The total model explains 32% of the variance in the ownership links between the 24,769 pairs of cities included in the data without missing values. The first variable emphasized by the model of stepwise multiple regression is O_INTRA_URB_LINKS, the number of intra-urban links among owner cities (with a partial R^2 11,6%). These results, while based on another scale, are consistent with those found by Wall et al. (2011) at the national level: the findings indicate that home advantage is highly significant in the internationalization of firms.

But moreover, this result means the predominance of the complexity of linkages inside the owner cities to determine the weight of the links. It is unsurprising as this finding underlines the role of city resources in controlling external subsidiaries. Such resources might include specialized services, institutions, high productivity and highly skilled workers. The relationship between local and global links is emphasized here, especially given the power functions in cities, confirming studies regarding "global cities" and "clusters" that suggest that this relationship exists at the micro-level (Sassen, 1991; van den Berg et al., 2001; Bathelt et al., 2004; Grabher, Powell, 2004). Of course, the density of the intra-urban relationships within owner cities is stronger among large cities (Tab. II): the high simple linear correlation between the logarithms of both variables (densities of intra-urban links [O_INTRA_URB_LINKS] and size of the cities [O_POPULATION]) is positive and quite significant (R=0.547).

This effect of intra-urban density is weaker for subsidiaries cities but continues to be important; this is the second-place variable in the stepwise multiple regression (partial R^2= 10,2%), together with the effect of population size for urban areas ((S_POPULATION: partial R^2=2,1%). Geographic distance matters for partial R^2= 4%, whereas other types of distance have a significant but weaker effect.

National indicators for cities have only a very limited influence on the total model. However, national development is in part considered in the urban indicators, as shown by the high correlations between the intra-urban links and national GDP per inhabitant, which is greater for subsidiary cities than for owner cities (Tab. II). Nevertheless, for owner cities, intra-urban links are more related to national wealth (GDP/inhab.) than to their total markets (GDP). The same is true for subsidiary cities, but the relationships are much more intense. Urban/national relationships are quite complex: the density of inter-urban links between national cities seems to play a (low) negative role in these flows (Tab. I). In fact, the national density and intra-urban density of links are negatively correlated for owner cities but positively correlated with subsidiary cities (Tab. II). It reveals the greater concentration of ownership links in few cities for many countries, even for some of the more developed ones.

The various multiple regressions by continent indicate better adjustment of the gravity model inside continents than between them (Tab. I). The gain is not strong for each continent, especially if one considers that the number of pairs for each continent is much lower than the total, making the explained variance much more likely to be higher (except for the Middle East, whose results are not significant, with very few links). However, North America, Asia and Europe, which have many more observations than the other continents, have higher R^2 values than the total value. For Asia and Europe, distance appears with a stronger effect than it does for other continents. For both continents, inter-city links are much more sensible to distance than in North America, where this influence is especially weak. The inter-continental effect of distance is obviously weaker. It is also notable that for Africa, which has very few links, the only significant variable in its inter-cities linkages is the national density of inter-urban links. This finding reflects the status of the rare African countries that have several cities that are integrated via FDI flows, such as South Africa.

The negative binomial regression confirms these results with a convergence of the model (Tab. III), highlighting only the significant variables. The only significant continental effects concern pairs of cities inside Europe, inside Asia, and between Europe and Asia and Europe and Africa: These couples of continents have more intense positive effect on the links, when compared to all other couples of continents, on average. However, the continental pattern of organization has some limitations that we can attempt to overcome by generating regional analysis based on empirical clustering for the entire matrix.

5. INSERTION INTO DENSE NETWORKS: REGIONALIZATION BY CLUSTERING

The regionalization of the world within large matrixes is a significant issue in network analysis, and several means of identifying relatively denser and more coherent regions (also called communities or clusters) have been suggested (Girvan & Newman, 2001; Auber *et al*. 2003, Clauset *et al*., 2004; Guimera *et al*., 2004, 2007; Guimera & Amaral, 2005; Newman *et al*., 2006; Newman, 2011). These methods form "*an entire family of techniques, with a single principle: if we can derive a measure of how strongly nodes in a network are connected together, then by grouping the most strongly connected we can divide the network into communities*" (Newman, 2012, p.26). Although Alderson and Beckfield (2004) used the *block modeling of regular equivalent* nodes to identify cities with the same relationships; physicists criticize this method because it does not sufficiently consider local density (Clauset *et al*., 2004). In fact, the defined communities must possess not only a high level of dependency between their members but also a low level of "vulnerability" generated by numerous redundancies (Jaccard, 1902; Burt, 2000, 2005). Studies in sociology and (more commonly) physics and biophysics have investigated large networks (Clauset et al., 2004). Newman et al. (2006) and Guimera et al. (2004, 2005, 2007) developed many clustering models based on "modularity", which identifies communities by maximizing intra-group linkages relative to inter-group ones.

Modularity is defined as follows (Girvan & Newman, 2001; Clauset *et al.*, 2004; Newman, 2012):

$$Q = \frac{1}{2m} \times \sum_{vw} \left[A_{vw} - \frac{k_v k_w}{2m} \right] \delta(c_v, c_w)$$

where

$A_{vw} = \begin{cases} 1 \\ 0 \end{cases}$ is an edge of the graph between nodes *v* and *w* (1 if v and w are connected; 0 otherwise)

$k_v = \sum_w A_{vw}$ is the degree of *v* and $k_w = \sum_v A_{vw}$ is the degree of *w*

$m = \frac{1}{2} \sum_{vw} A_{vw}$ is the total number of possible non-oriented edges in the graph

$\delta(c_v, c_w)$ is the community function for v and w: 1 if v and w are in the same community; 0 otherwise

For Clauset et al. (2004) and Newman (2012), who employ undirected and non-weighted graphs, the last parameter $\delta(c_v, c_w)$ implies that only intra-community links are measured. High values for the Q index of modularity indicate that the network is clearly divided into communities (according to Clauset *et al.* [2004], a value above approximately 0.3 indicates a significant community structure), and the maximum value of Q indicates the best clustering. This method has the advantage of not *a priori* establishing the number of communities.

For the oriented and weighted links, as with the ownership linkages between cities, the measure of modularity is insufficient because of the high dispersion of the values at the edges (Newman, 2012). Based on the foundations of this model (which is a "*Hamiltonian of a (disordered) Potts model*" [Newman, 2012]), a group of physicists generalized this Hamiltonian Potts model, developing the "*spin glass clustering methods*" usually applied to the physics of materials (inhomogeneous ferromagnetic materials), which often require oriented and weighted interaction models (Blatt *et al.*, 1996; Reichardt, Bornholdt, 2006; Traag, Bruggemann *et al.*, 2008; Sathik *et al.*, 2011). The spin glass methods use the Hamiltonian Potts model $\mathrm{H}\left[\{s\}\right]$ of a partition *s* that measures the distance between the nodes according to their direct or indirect links to the networks J_{vw} and based on their membership within the classes being partitioned $\delta(s_v, s_w)$:

$$\mathrm{H}\left[\{s\}\right] = -\sum_{vw} J_{vw}\delta(s_v, s_w)$$

The spin glass model takes into account the existing links as well as the missing links inside and outside each class. Then, $\mathrm{H}\left[\{s\}\right]$ is calculated for 4 cases (Reichardt, Bornholdt, 2006):

$$\mathrm{H}\left[\{s\}\right] = \underbrace{-\sum_{v\neq w} a_{vw}J_{vw}\delta(s_v, s_w)}_{internal\_links} + \underbrace{\sum_{v\neq w} b_{vw}(1-J_{vw})\delta(s_v, s_w)}_{internal\_non\_links} + \underbrace{\sum_{v\neq w} c_{vw}J_{vw}(1-\delta(s_v, s_w))}_{external\_links} + \underbrace{\sum_{v\neq w} d_{vw}(1-J_{vw})(1-\delta(s_v, s_w))}_{external\_non\_links}$$

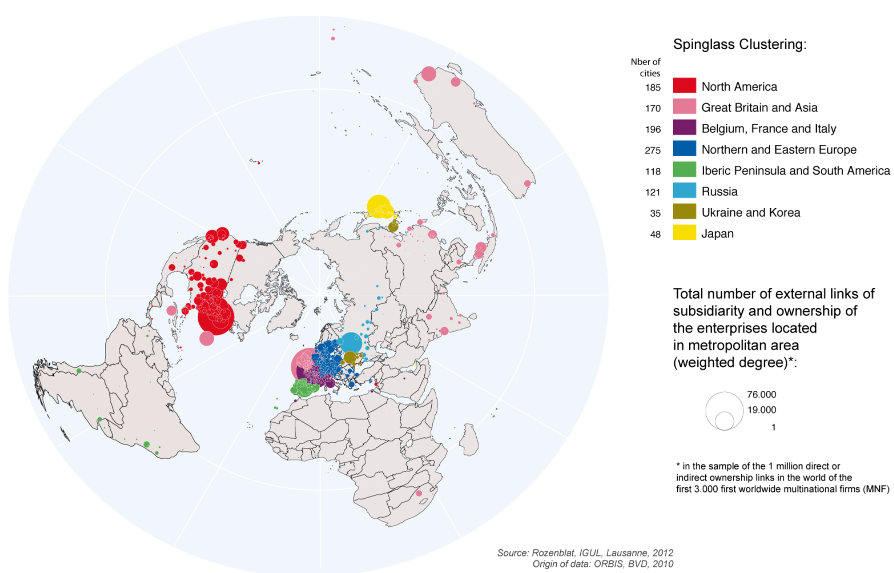
Thus, the model measures both intra-community and inter-community links, evaluating the "*temperature*", which is minimized when the network is far to randomly graph (Blatt et al., 1996). It calculates different partitions (called spin states), maximizing their modularity, in the same way as Clauset et al. (2004) or Newman (2006, 2012).

5.1 Spin glass clustering for cities according to their positions within the ownership networks of MNF

We applied the spin glass model to the network of multinational firms between cities (tab. IV). 'Good' clustering depends on the maximization of the modularity index and the minimization of the "temperature". Thus, we choose S8 clustering configuration, partitioning the 8 classes with the second highest modularity but with a lower temperature than S5 configuration. In this way, we obtain the 8 classes of cities presented in figure 6.

Figure 6

Clustering of world metropolitan areas according to their links of ownership/subsidiaries of MNF



The resulting 8 classes are sometimes delineated by continents consistent with the positive residuals finds by Grasland and Didelon (2008), but some other times not, corresponding more to global integrations:

- North America remains a unique class; it includes some South American cities (Panama, Veracruz, Medellin and Tijuana) but also includes Zürich in Europe and Tel Aviv.
- Most cities in Asia and Oceania are grouped with London and the British cities (and with tax havens such as Bermuda Kindley and the Cayman Islands); thus, British cities are relatively isolated from other European cities.
- Apart from the British cities, Europe is divided into three classes:
    - Belgium, French and the Italian cities, which are relatively more integrated with each other than with the other European cities;
    - The Spanish and Portuguese cities, which are grouped with the South American ones;
    - Germany, Switzerland, Austria and Netherland are grouped with Scandinavian cities and the Eastern cities of new member States of the European Union.
- The Ukraine and South Korea are grouped together because of the subsidiaries of firms from Seoul that are located in Kiev, a large Ukrainian network with three main groups: LG Electronics, Samsung and Hyundai.
- Japanese cities form an isolated group; not only are they more nationally integrated than is typical (60%), but these linkages are centered on Tokyo and are quite evenly distributed between Great Britain, North America and the three European groupings. This class includes also Dubai, Abu Dhabi and Doha.
- Russian cities, including those of the new states formerly part of the Soviet Union, are significantly isolated from the rest of the network.

Most of these classes are centered on individual regions, and the effect of distance seems to influence them even though distance was not taken into account as part of the clustering process.

5.2 Gravitation model applied to the classes generated by the spin glass clustering process

The gravitation model was again applied to these classes using multiple log-linear regression (Tab. V). Excellent results were achieved, as all intra-class models had significant R^2 values, greater than the average model values at 32%. However, these R^2 values cannot really be interpreted insofar as their values depend on the number of observed pairs in each class. However, the higher R^2 values of these classes do indicate the more homogeneous behavior of firms inside these classes. We obtained extremely high R^2 values for Belgium, France and Italy (R^2=0.49 with more than 1,000 pairs of cities), Russia (R^2=0.57 with 353 observations) and Japan (R^2=0.62 with 187 observations). The differences between some of the parameters indicate specific patterns for particular classes. For instance, the effect of the intra-urban links for owner cities is much higher for the North American cities in the S7 class (and for Japanese cities [S3] and those in Spain, Portugal and South America [S0]) than for the European cities in classes S4 and S6.

The negative binomial regression confirms the effects of distance and class (Tab.VI). Based on their class, owner or subsidiary cities may be more or less likely to integrate into multinational firm networks. The estimated values in table VI indicate the positive or negative effects of class membership on the weight of the linkages between pairs of cities. First, all of the intra-class links have a positive effect on the strength of the links between cities. This is especially true for the Ukraine and Korea and for Russia, which demonstrates a low level of openness to the other classes. This effect indicates the stronger links between the cities inside each class. Second, between cities in different classes, the highest values are unsurprisingly from owner cities of different classes to the North American cities (S7).

Finally, the results of the spin glass clustering procedure are confirmed by these different analyses, which more fully characterize each class in terms of its internal and external interaction levels. To understand these forms of organization, we now describe these classes in greater depth.

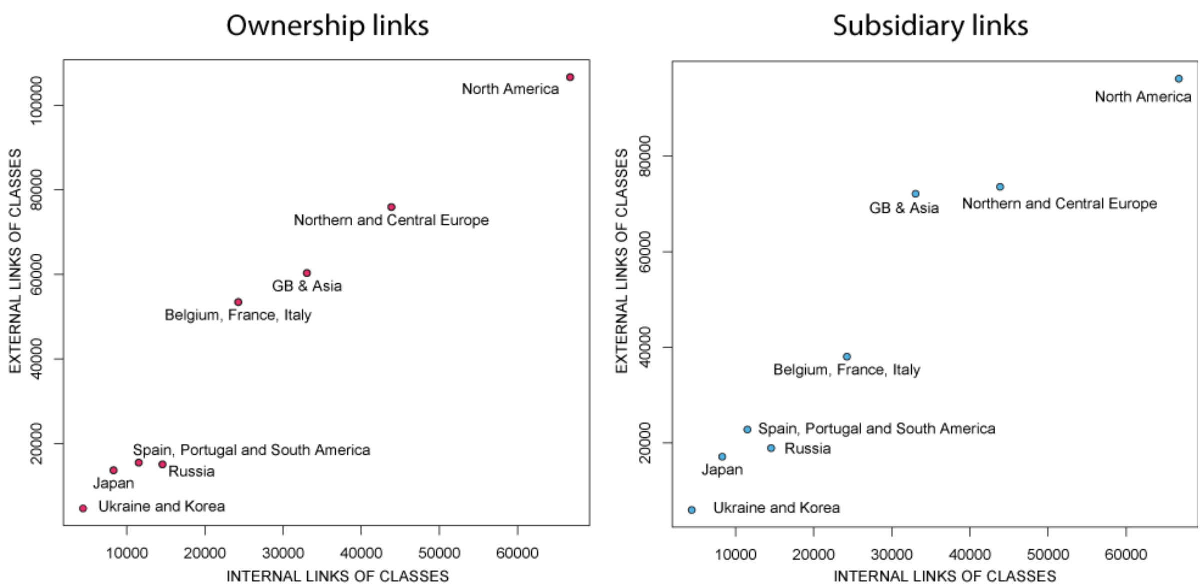
5.3 Description of the classes generated by the spin glass clustering procedure

The organization of the classes can be characterized based on their balance of internal/external relationships (5.3.1), their mutual relationships (5.3.2), and their internal hierarchies of cities, in which central cities exhibit most of the links inside each class and serve as bridges to the outside (5.3.3).

5.3.1 Internal and external densities of links

The more basic information about each class has to do with the balance between the internal and external links for that group. This information is obtained by summing the weighted links of all of the cities in a class (removing intra-urban links), and retaining both the intra-class and the inter-class links. Unsurprisingly, North America has a greater number of internal and external links, and Europe is divided into four parts (Fig. 7). More surprisingly, all of the classes have relatively equal proportions of inter/intra links. This seems to be one of the properties of spin glass clustering that has not been mentioned in the literature as far as we know.

Figure 7: Classes of the Spin Glass clustering of World Metropolitan areas according to their internal and external links of ownership/subsidiary

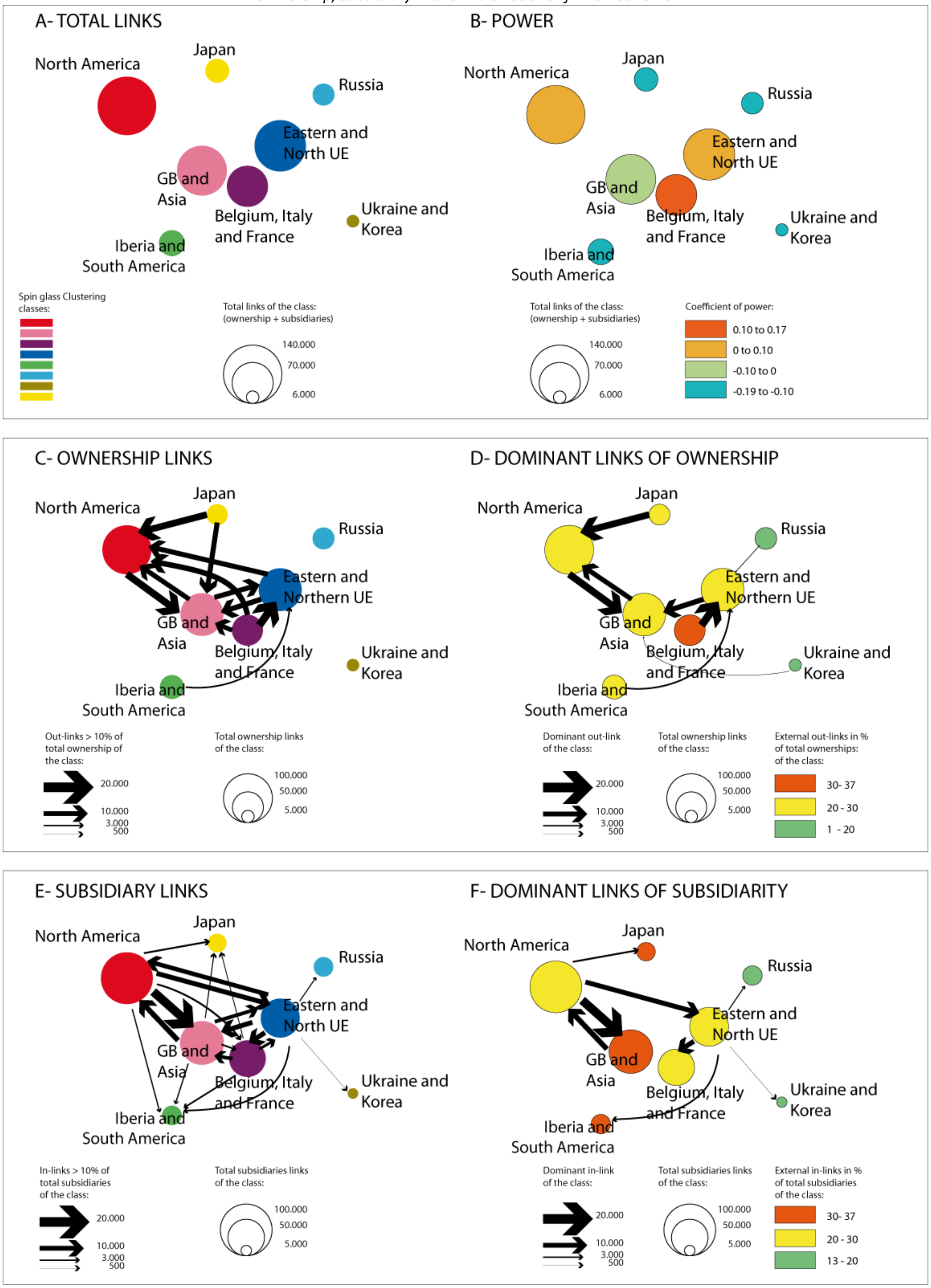


5.3.2 Organization of city networks between classes

The second piece of information is the power position of each group (Fig.8-B). We calculated the *coefficient of power* as the relative difference between the out-degrees and in-degrees (all weighted) based on only the inter-class links:

$$Power_c = \frac{interclass\_ownership\_links_c - interclass\_subsidiary\_links_c}{interclass\_ownership\_links_c + interclass\_subsidiary\_links_c}$$

Figure 8: Clustering classes of World Metropolitan areas according to their global position of ownership/subsidiary in the Multinational firms networks



This power coefficient falls between -1 and +1:

- If the coefficient is equal to -1, then all of the out-links for this class are subsidiary links (in-degree). This means that the cities within this class are collectively dependent on the cities within the other classes;
- If the coefficient is equal to +1, then all of the out-links for this class are ownership links (out-degree). This means that the cities within this class collectively dominate the cities of the other classes;
- If the coefficient is close to 0, the ownership and subsidiary links are balanced.

Here, all of the classes have power coefficients that are close to 0, which indicates the good equilibrium between the ownership and subsidiary links (Fig.8-B). There are only a few trends that distinguish the more powerful classes (Belgium, France and Italy; North America; Eastern and Northern Europe) from the more dependent classes (Great Britain and Asia and all other groups). The detailed aggregated relationships between the classes are specified for ownership links (Fig.8-C and Fig.8-D) and for subsidiary links (Fig.8-E and Fig.8-F).

The relatively higher percentage of ownership relationships that exist independently within each class (with >10% of the total ownership comprised of intra-class ownership) indicates the almost complete closure of Russia and Ukraine/South Korea with regard to ownership (Fig.8-C). This finding is confirmed by the low share of external ownership as compared to internal ownership within these two classes (Fig.8-D). The rest of Russia and Ukraine/South Korea class' external ownership is not concentrated in a single other class, and its "dominant" external ownership link is still very weak (Fig.8-D). (The "dominant" link in network analysis is the strongest link [Nuysten & Dacey, 1961]. Here, we selected the highest external ownership links for each class.) The other classes are much more integrated by a dense network of ownership links. In the only "dominant" ownership links between classes, Europe is linked to North America via the Great Britain-Asian class (Fig.8-D). Belgium, France and Italy constitute the most open group with regard to ownership (with 37% of the total ownership links), whereas Great Britain and Asia constitute the most central class within the system.

The subsidiary links (in-links) exhibit a very similar pattern (Fig.8-E and fig.8-F). However, Russia and Ukraine/South Korea are no longer isolated, with stronger subsidiary links with the Eastern and Northern European class. This group of Eastern and Northern European cities is now the most central class in the system of dominant subsidiaries links; it is principally dominated by North America (as its subsidiary) and dominates four other classes (as the owner).

5.3.3 Organization of city networks within classes

Each class has an internal organizational structure that is centered on one or few nodes or decentralized with a very dense internal interconnected network of cities. The roles of nodes have been evaluated using *structural equivalence* and *block models* since Nadel (1957) and White and co-workers (Lorrain & White, 1971; White et al. 1976) (for a synthesis of these models, see also Wasserman & Faust, 1994; Scott, 2000). However, Guimera and Amaral (2005) demonstrated the limitations of these approaches, proposing some indexes that can be used to categorize the roles of different nodes in clustering classes.

Guimera and Amaral (2005) proposed two types of indexes. The *z-score index* of a node *v* inside a class *c* measures how many of the node's connections contribute to the connectivity of the class, whereas its *participation coefficient* evaluates its connections to the other clusters.

The *z-score index* z_v is defined as follows by Guimera & Amaral (2005)*:*

$$z_v = \frac{k_{v_c} - \overline{k}_{c_v}}{\sigma_{k_{c_v}}}$$

where

k_{v_c} is the number of links *k* of the node *v* in class *c*

$\overline{k}_{c_v}$ is the average number of links *k* of all nodes in *v*'s class c_v

$\sigma_{k_{c_v}}$ is the standard deviation of the links *k* of all nodes in *w*'s class c_v

The *participation index* P_v is defined by Guimera & Amaral (2005) as

$$P_v = 1 - \sum_{c=1}^{M} \left(\frac{k_{v_c}}{k_v} \right)^2$$

where

k_{v_c} is the number of links *k* of node *v* in *all classes c=1 to M*

k_v is the total number of links *k* for node *v*

One can make at least three criticisms of these indexes (Rozenblat, Melançon, 2009):

1- They are applied only to links that are not weighted (also in Guimera *et al*., 2005);

2- The distribution of the number of links inside a class is often far from having a normal distribution; thus, the average and standard deviation are not helpful. For weighted graphs, the asymmetry of the distribution will be worse;

3- The two indexes provide only somewhat symmetrical information, as they do not consider the position of the node in the network at the same level: the z-score is for one class, whereas the participation index is for all of the classes.

Thus, as a means to evaluate the role of each node in its own class, we propose the use of two complementary indexes at the levels of the node and its class, respectively (Rozenblat, Melançon, 2009). Borrowing from the vocabulary of multivariate analysis, where each individual or each variable is "represented" on each factor (the % of the individual variance taken into account on the factor), we define a "*representation*" of each node based on its class as the percentage of the total weighted links of the nodes maintained in its class (with other nodes inside its class).

The *representation* of node v_i based on its class *c* can be represented as follows:

$$repr_{v_i}^{c} = \frac{Deg_{v_i}^{c}}{Deg_{v_i}}$$

where

$Deg_{v_i}^{c}$ is the weighted degree of node v_i (the sum of weighted links) in its class *c*

Deg_{v_i} is the total weighted degree of v_i.

Similarly, as in multivariate analysis, we can define the "*contribution*" of a node *v* to its class *c* as the percentage of the total weighted links of class c that are concentrated on node *v*.

$$Contr_{v}^{c} = \frac{Deg_{v}^{c}}{\sum_{v=1}^{n} Deg_{v}^{c}}$$

where $\sum_{v=1}^{n} Deg_{v}^{c}$ is the total number of all the n nodes v of class c.

Figure 9-A: Intra-class measurements of “representations” and “contributions” for owner cities

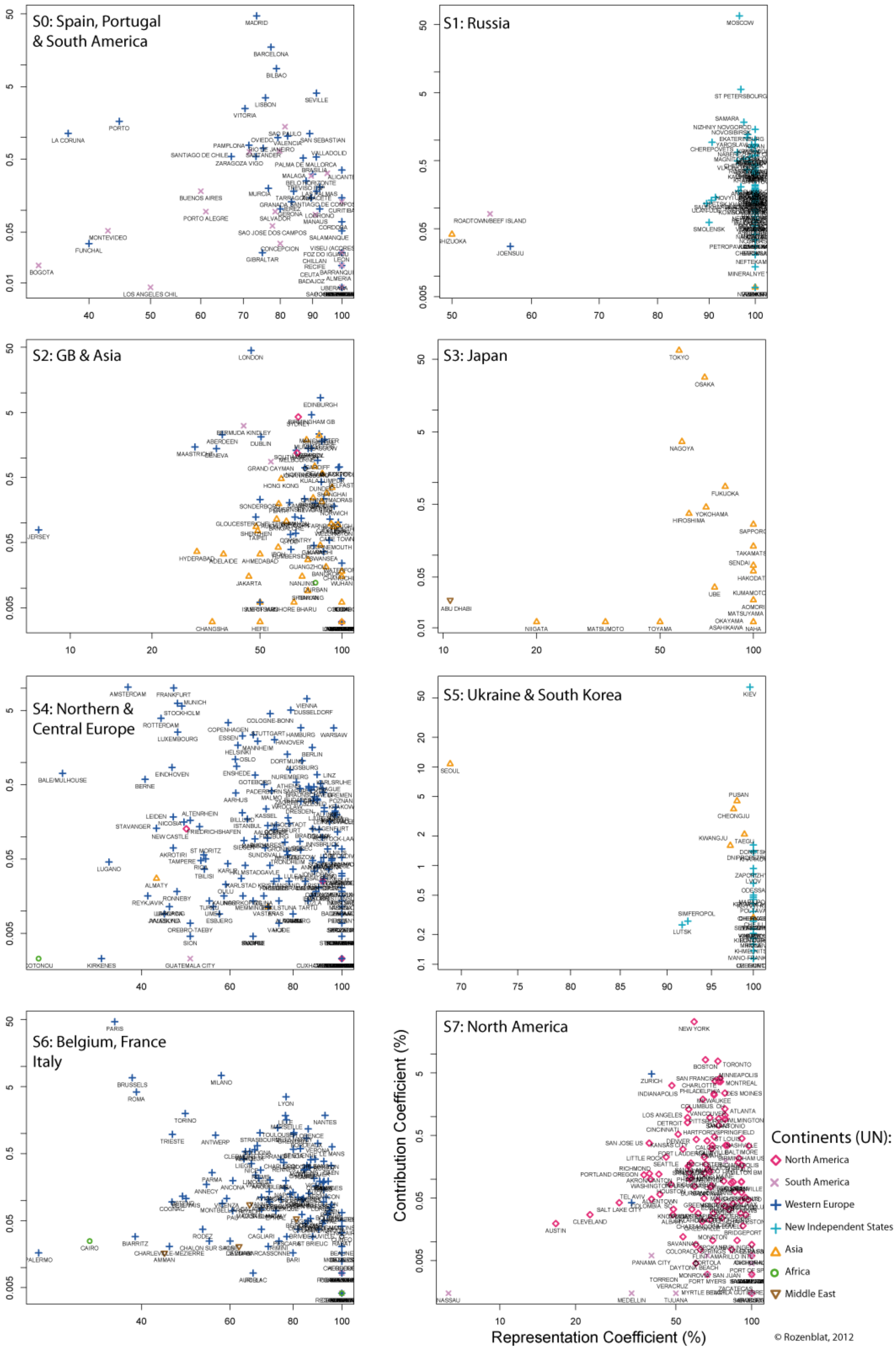
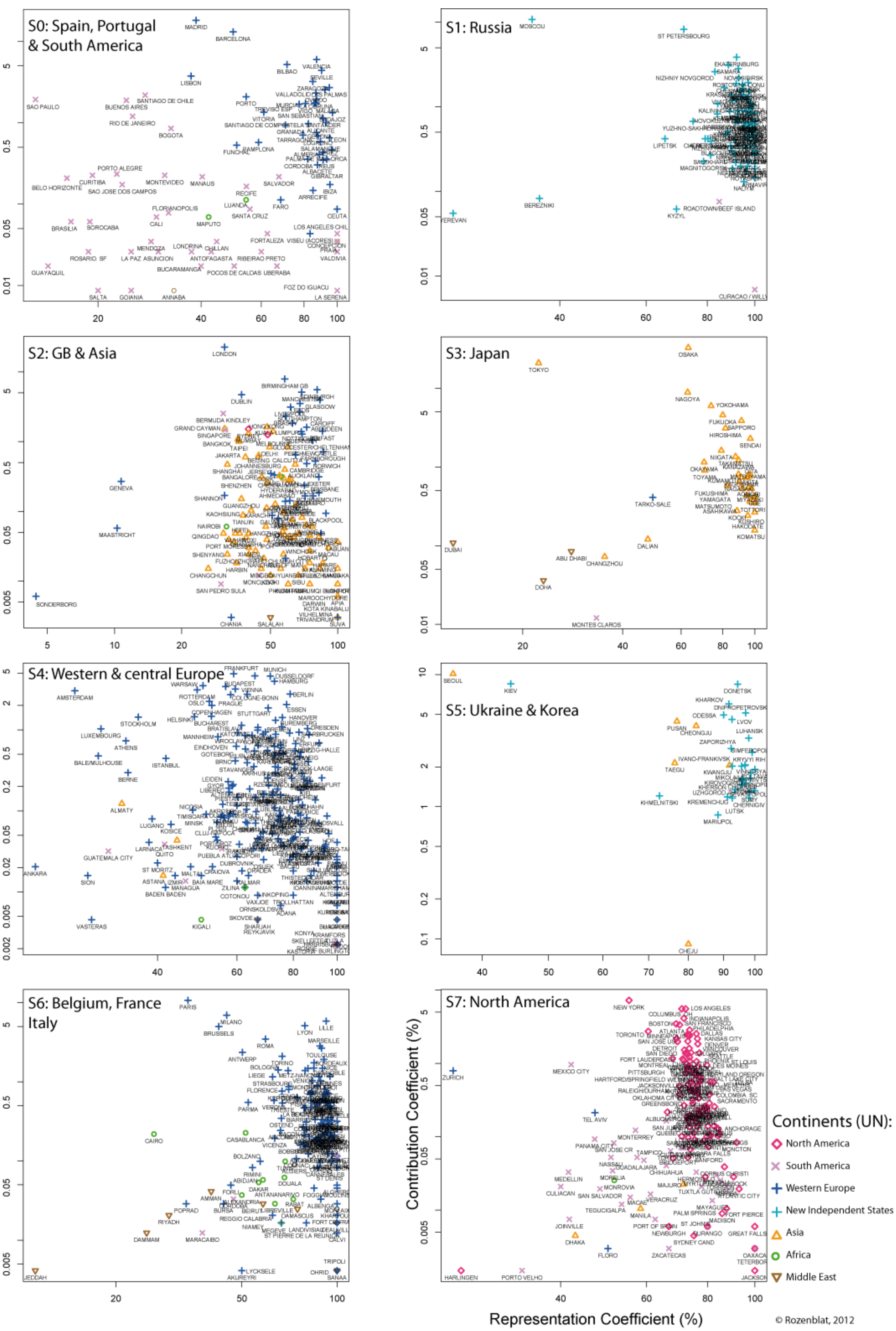


Figure 9-B: Intra-class measurements of "representations" and "contributions" for subsidiary cities



The use of these indexes to evaluate the balance of the links of a node between different classes is discussed in Rozenblat & Melançon (2009). For a given cluster, the computation of these indexes is easy. The measure was applied to the 1,205 cities distributed among the 8 classes using the representations and contribution indexes for each city in each class. We used two different measures: one for the in-links (subsidiary links) (fig. 9-A) and another for the out-links (ownership links) (Fig. 9-B).

The center-periphery system of owner cities for each class is visible on the y-axis for the contributions (Fig.9-A: y-axis). The intra-class *contributions* of cities in terms of ownership generally indicate the domination of a single city that contributes approximately 50% of the total intra-links for its own class: Madrid, Moscow, London, Tokyo and Osaka, Kiev and Seoul, Paris and New York are in this position. The only class that does not follow this pattern is the Northern and Central European class, in which numerous cities make an equivalent contribution to their class: Amsterdam, Frankfurt, Munich, Stockholm, Vienna, Dusseldorf, Cologne-Bonn, Rotterdam, Copenhagen and Luxemburg are the principal cities.

The findings regarding the intra-class *representation* of cities with regard to ownership (Fig.9-A: x-axis) indicate a distinction between classes in which most of the cities are very strongly represented by their class and those in which this is not the case. The former include Russia, Japan and Ukraine/South Korea, while Northern and Central Europe is the most open class.

The crossed intra-class *contributions* and *representation* of owner cities underline the role of "bridge" cities in controlling cities in other classes (Rozenblat, Pumain, 2006). The cities with low representation and high contributions can be considered "bridges" to the cities within their classes (top left of the graphs), especially when the other cities in the class are very well represented in the class (meaning that their links are mostly inside the class). Again, we find all the dominant cities in each group, but we also find other cities that are not as dominant and have lower representation within their own group: for example, La Coruna and Porto in the S0 class, Roadtownbeek island in the S1 class, Jersey in the S2 class, and Basel in the S4 class.

The intra-class *contributions* and *representation* of cities as subsidiaries (Fig.9-B) exhibit the same type of patterns for each class, but the hierarchy of contributions is much lower; it is never higher than 8%. The intersecting intra-class *contributions* and *representation* of subsidiary cities underline the role of "bridge" cities in investment coming from outside the class. This is the case for Sao Paulo as compared to the other South American cities in class S0, Geneva, Maastricht or tax havens such as Bermuda Kindley, Grand Cayman, Singapore, Tokyo (in comparison to Osaka), and Zurich for North American cities.

Even if the position of each city is different for the two types of graphs, the stability of the pattern for each class reveals the importance of urban frameworks based on international economic proximity and indicates the strong structural effect of intra-class organization. In both figures 9-A and 9-B, the very centralized classes (e.g., Russia or Ukraine and Korea) remain highly concentrated. Japan, with the contributions of Tokyo and Osaka, is quite open, but most of the Japanese cities are quite confined within the national urban network (consistent with the structure observed in the 1980s at the firm levels by Westney & Sakakibara [1985]). However, the Japanese case is not an exception; most of the classes include very integrated cities, with few cities exhibiting links outside the class. Only four European classes that are extremely close to each other do not exhibit this pattern.

CONCLUSION

This paper aims to measure the integration of cities in global firm networks using a multi-scale structure that includes intra-urban linkages and national, continental and inter-continental links. The share of inter-continental links is rather low; these networks largely develop at the national scale. The national scale remains essential to the economic integration of cities in global networks, as it contains two thirds of the total inter-urban linkages. However, the main factor that explains the flows of ownership between cities is the local density of links inside each city. This finding demonstrates the attractiveness of a well-connected local urban economy in foreign investment. Whereas some contend that only economic factors influence global investment, geographic distance does remain a significant factor.

We have shown that in analyses of foreign investment, the city scale has advantages over the national scale in capturing a variety of effects, from urban to national and continental. We were able to identify classes that strongly influence the structure of the system and that have not been previously identified. The classes correspond sometimes to continents or part of continents, but not so basically: The classes containing British cities with Asian ones, or the one of Ukraine with Korea, or the division of Europe, were not expected. Also the belonging of some cities to classes of other continents are sometimes not surprising, as Zürich to the North American class, but other times more uncommon as Abu Dhabi, Doha and Dubai to the Japanese class.

The resulting eight classes reflect the strong integration of cities within sub-networks that are each dominated by one or a few cities that act as "bridges" between classes. Thus, London, New York, Paris, Moscow, Seoul, Tokyo, Madrid, Barcelona, and (to a lesser degree) Amsterdam, Zürich and Sao Paulo are of great importance to the organizational framework of the global network because of their prominent position in their own class. However, the British and Asian class is the more central one for ownership, dominating directly or indirectly the other classes, except Russia and South Korea and Ukraine, which remain isolated from the other classes.

These classes are important to consider because they may either change under the influence of various international agreements or become even better defined. In the future, the central cities in each of these classes will reap the advantages of existing inter-class links; they will be able to strengthen their initial position in their respective networks. According to the models developed by physicists, such networks are highly likely to provide more advantages to these cities in the future via processes of "preferential attachment" that intensify their role as bridges between classes (Albert, Barabasi, 1998). These "scaling laws" are presumed to reinforce the hierarchy of cities based on their initial differential conditions. Diachronic studies will confirm or disprove this thesis in the future, and simulations will help to calibrate different parameters for these multi-level dynamics of change in the world cities system.

However, one limitation of the urban approach is that it does not take into account the strategies of firms based on different geographic scales. To identify the possible regulations governing these networks, one also must consider the strategies of firms, which may be economic (e.g., concurrence, alliances, sub-contracting, division of labor, product cycles) or managerial (i.e., innovation in the global organization of firms), and which influence these different scales. Thus, integrating the "global value chain" of these networks via a multi-dimensional approach to the interaction between the reach of individual firms and that of particular territories may yield fresh, new research. Such research can effectively address the micro-networks of firms that exist inside and between countries, inside and between cities and inside and between macro-regions.

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APPENDICES

Table I: Gravitation model of the MNF ownership flows between cities by continent (Multiple linear regression)

	TOTAL			CONTINENT OF OWNER CITY DIFFERENT TO CONTINENT OF SUBSIDIARY CITY			AFRICA			ASIA		
R^2			0.32			0.35			0.49			0.43
Pr > F			<.0001			<.0001			0.017			<.0001
nber of observations			24'769			10'072			24			649
Parameters*	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F
LOG_O_POPULATION_URB	0.016	0.195	<.0001	0.006	0.145	<.0001				0.037	0.322	<.0001
LOG_O_INTRA_URB_LINKS	0.116	0.223	<.0001	0.129	0.235	<.0001				0.163	0.263	<.0001
LOG_O_NATIONAL_GDP	0.012	0.200	<.0001							0.007	-0.060	0.005
LOG_O_NATIONAL_GDP/INHAB				0.003	0.074	<.0001						
LOG_O_INTRA_NAT_LINKS	0.002	-0.100	<.0001	0.004	-0.412	<.0001						
LOG_S_POPULATION_URB	0.021	0.200	<.0001	0.011	0.128	<.0001						
LOG_S_INTRA_URB_LINKS	0.102	0.204	<.0001	0.175	0.188	<.0001				0.115	0.134	<.0001
LOG_S_NATIONAL_GDP				0.005	0.205	<.0001				0.006	-0.013	0.010
LOG_S_NATIONAL_GDP/INHAB	0.007	0.147	<.0001	0.002	0.085	<.0001				0.005	0.165	0.020
LOG_S_INTRA_NAT_LI	0.001	-0.168	<.0001	0.003	-0.175	<.0001	0.226	0.330	0.017			
LOG_DIST	0.040	-0.304	<.0001	0.001	-0.106	<.0001				0.093	-0.524	<.0001
LOG_R_GDP_INHAB	0.001	0.072	<.0001									
LOG_R_GDP	0.002	-0.111	<.0001	0.013	0.138	<.0001						

	EUROPE			SOUTH AMERICA			NORTH AMERICA			MIDDLE EAST		
R^2			0.37			0.38			0.51			0.72
Pr > F			<.0001			<.0001			<.0001			0.09
nber of observations			9'913			248			3'844			13
Parameters*	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F
LOG_O_POPULATION_URB	0.009	0.180	<.0001				0.010	0.166	<.0001			
LOG_O_INTRA_URB_LINKS	0.122	0.277	<.0001	0.137	0.126	<.0001	0.308	0.540	<.0001			
LOG_O_NATIONAL_GDP							0.001	0.582	0.005			
LOG_O_NATIONAL_GDP/INHAB							0.003	-5.263	<.0001			
LOG_O_INTRA_NAT_LINKS	0.000	-0.090	0.01									
LOG_S_POPULATION_URB	0.046	0.031	<.0001	0.026	0.189	0.001	0.008	0.215	<.0001			
LOG_S_INTRA_URB_LINKS	0.092	0.134	<.0001	0.141	0.065	<.0001	0.145	0.266	<.0001			
LOG_S_NATIONAL_GDP	0.008	-0.125	<.0001				0.007	0.291	<.0001			
LOG_S_NATIONAL_GDP/INHAB												
LOG_S_INTRA_NAT_LI							0.002	-0.615	<.0001			
LOG_DIST	0.086	-0.635	<.0001	0.064	-0.249	<.0001	0.016	-0.194	<.0001			
LOG_R_GDP_INHAB												
LOG_R_GDP	0.004	-0.054	<.0001									

Only estimated values with Pr > F below 5% are indicated

Table II: Correlation matrix of all logarithms of variables

Mentioned indexes:
- **Correlations indexes: R**
- Pr > F
- Number of observations without missing values

	LOG_LINK	LOG_O_POPULATION_URB	LOG_O_INTRA_URB_LINKS	LOG_O_NATIONAL_GDP	LOG_O_NATIONAL_GDP/INHAB	LOG_O_INTRA_NAT_LINKS	LOG_S_POPULATION_URB	LOG_S_INTRA_URB_LINKS	LOG_S_NATIONAL_GDP	LOG_S_NATIONAL_GDP/INHAB	LOG_S_INTRA_NAT_LI	LOG_DIST	LOG_R_GDP_INHAB	LOG_R_GDP
LOG_LINK	1													
	33,483													
LOG_O_POPULATION_URB	**0.227**	1												
	<.0001													
	30,151	30,151												
LOG_O_INTRA_URB_LINKS	**0.328**	**0.547**	1											
	<.0001	<.0001												
	33,396	30,064	33,396											
LOG_O_NATIONAL_GDP	**0.039**	**0.021**	**0.015**	1										
	<.0001	0.0003	0.007											
	33,419	30,124	33,332	33,419										
LOG_O_NATIONAL_GDP/INHAB	**0.058**	**-0.275**	**0.179**	**0.202**	1									
	<.0001	<.0001	<.0001	<.0001										
	33,419	30,124	33,332	33,419	33,419									
LOG_O_INTRA_NAT_LINKS	**-0.019**	**0.207**	**-0.107**	**0.625**	**-0.400**	1								
	0.0006	<.0001	<.0001	<.0001	<.0001									
	33,441	30,111	33,354	33,377	33,377	33,441								
LOG_S_POPULATION_URB	**0.124**	**-0.017**	**-0.119**	**-0.023**	**-0.075**	**0.017**	1							
	<.0001	0.0062	<.0001	0.0001	<.0001	0.0044								
	29,081	26,266	29,004	29,027	29,027	29,046	29,081							
LOG_S_INTRA_URB_LINKS	**0.254**	**-0.186**	**-0.177**	**0.020**	**0.025**	**0.008**	**0.349**	1						
	<.0001	<.0001	<.0001	0.0002	<.0001	0.1391	<.0001							
	33,476	30,145	33,389	33,412	33,412	33,434	29,076	33,476						
LOG_S_NATIONAL_GDP	**0.097**	**-0.030**	**-0.036**	**0.241**	**0.118**	**0.078**	**-0.064**	**0.156**	1					
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001						
	33,294	29,975	33,208	33,232	33,232	33,254	28,981	33,293	33,294					
LOG_S_NATIONAL_GDP/INHAB	**0.119**	**-0.125**	**-0.038**	**0.163**	**0.271**	**-0.034**	**-0.363**	**0.348**	**0.461**	1				
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001					
	33,294	29,975	33,208	33,232	33,232	33,254	28,981	33,293	33,294	33,294				
LOG_S_INTRA_NAT_LI	**0.080**	**-0.056**	**-0.058**	**0.098**	**-0.029**	**0.090**	**-0.078**	**0.289**	**0.742**	**0.357**	1			
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001				
	33,270	29,962	33,183	33,206	33,206	33,238	28,887	33,263	33,081	33,081	33,270			
LOG_DIST	**-0.141**	**0.223**	**0.132**	**0.098**	**0.014**	**0.042**	**0.276**	**-0.045**	**-0.033**	**-0.235**	**-0.167**	1		
	<.0001	<.0001	<.0001	<.0001	0.0166	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001			
	31,308	28,399	31,224	31,248	31,248	31,279	27,609	31,305	31,126	31,126	31,120	31,308		
LOG_R_GDP_INHAB	**-0.074**	**-0.063**	**0.156**	**-0.020**	**0.412**	**-0.236**	**0.292**	**-0.313**	**-0.358**	**-0.765**	**-0.360**	**0.225**	1	
	<.0001	<.0001	<.0001	0.0004	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		
	33,232	29,949	33,146	33,232	33,232	33,192	28,928	33,231	33,232	33,232	33,019	31,068	33,232	
LOG_R_GDP	**-0.053**	**0.043**	**0.042**	**0.565**	**0.055**	**0.414**	**0.035**	**-0.118**	**-0.665**	**-0.267**	**-0.550**	**0.103**	**0.289**	1
	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	
	33,232	29,949	33,146	33,232	33,232	33,192	28,928	33,231	33,232	33,232	33,019	31,068	33,232	33,232

Table III: Gravitation model of the MNF ownership flows between cities with 7 continents
(Negative binomial regression. Number of observations 24,769)

Parameter°	Owner Continent	Subsidiary Continent	Estimated value	Standard Error	Wald confidence Interval at 95%		Khi2 of Wald	Pr > Khi-2
O_POPULATION_URB			0.0000	0.0000	0.0000	0.0000	2736.09	<.0001
O_INTRA_URB_LINKS			0.0000	0.0000	0.0000	0.0000	189.84	<.0001
O_NATIONAL_GDP								
O_NATIONAL_GDP/INHAB			0.0000	0.0000	0.0000	0.0000	86.66	<.0001
O_INTRA_NAT_LINKS								
S_POPULATION_URB			0.0000	0.0000	0.0000	0.0000	1429.01	<.0001
S_INTRA_URB_LINKS			0.0000	0.0000	0.0000	0.0000	373.45	<.0001
S_NATIONAL_GDP								
S_NATIONAL_GDP/INHAB			0.0000	0.0000	0.0000	0.0000	213.42	<.0001
S_INTRA_NAT_LI			-0.0014	0.0006	-0.0026	-0.0003	5.93	0.0148
DIST			-0.0001	0.0000	0.0000	-0.0001	157.42	<.0001
R_GDP_INHAB			-0.0201	0.0018	-0.0235	-0.0166	128.18	<.0001
R_GDP								
OCONTINENT*SCONTINENT	Asia	Asia	2.0975	0.8998	0.3339	3.8611	5.83	0.0198
OCONTINENT*SCONTINENT	Europe	Africa	1.4257	0.6366	0.168	2.6633	4.95	0.0262
OCONTINENT*SCONTINENT	Europe	Asia	1.9729	0.8251	0.3556	3.5901	5.72	0.0168
OCONTINENT*SCONTINENT	Europe	Europe	2.4278	0.5677	1.3151	3.5405	18.29	<.0001

Only estimated values with Pr > F below 5% are indicated, and only significant CONTINENT and COUPLES OF CONTINENTS are listed
The negative binomial dispersion parameter was estimated by maximum likelihood.

Table IV: Spin Glass clustering applied on the MNF ownership flows between cities
(number of observations: 28,376 links and 1,205 nodes)

Number of Spin states	Modularity	Number of effective classes	Temperature
S2	0.3088698	2	0.1720134
S3	0.3157702	3	0.03640213
S4	0.3296908	4	0.0477343
S5	0.3345973	5	0.1210024
S6	0.338596	6	0.09652922
S7	0.3379613	6	0.09088035
S8	0.3385766	8	0.1145915
S9	0.3292114	8	0.08470642
S10	0.3363199	10	0.1067709
S11	0.3352694	9	0.1100761
S12	0.3363024	10	0.105191
S13	0.3362109	9	0.1000356
S14	0.331702	11	0.09044
S15	0.3362194	11	0.1010121
S20	0.3358332	13	0.09955088
S25	0.333587	11	0.1046813
S30	0.3356406	12	0.09906852
S35	0.3351481	10	0.09144567

Table V: Gravitation model of the MNF ownership flows between cities by Spin Glass Classes (Multiple linear regression)

	TOTAL			CLASS OF OWNER CITY DIFFERENT TO CLASS OF SUBSIDIARY CITY			S0: Spain, Portugal & South America			S1: Russia			S2: GB & Asia		
R^2			0.32			0.34			0.54			0.58			0.42
Pr > F			<.0001			<.0001			<.0001			<.0001			<.0001
nber of observations			24,769			13,954			668			353			1024
Parameters*	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIA L R^2	Estim. Param	Pr > F	PARTIA L R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F
LOG_O_POPULATION_URB	0.016	0.195	<.0001	0.007	0.158	<.0001	0.019	0.185	<.0001	0.367	1.296	<.0001	0.022	0.204	<.0001
LOG_O_INTRA_URB_LINKS	0.116	0.223	<.0001	0.132	0.223	<.0001	0.259	0.403	<.0001				0.145	0.242	<.0001
LOG_O_NATIONAL_GDP	0.012	0.200	<.0001	0.007	0.111	<.0001									
LOG_O_NATIONAL_GDP/INHAB															
LOG_O_INTRA_NAT_LINKS	0.002	-0.100	<.0001	0.006	-0.349	<.0001									
LOG_S_POPULATION_URB	0.021	0.200	<.0001	0.017	0.163	<.0001	0.053	0.338	<.0001	0.180	0.704	<.0001	0.033	0.300	<.0001
LOG_S_INTRA_URB_LINKS	0.102	0.204	<.0001	0.160	0.182	<.0001	0.164	0.137	<.0001				0.154	0.165	<.0001
LOG_S_NATIONAL_GDP				0.001	0.041	<.0001							0.005	-0.195	0.002
LOG_S_NATIONAL_GDP/INHAB	0.007	0.147	<.0001	0.004	0.203	<.0001				0.012	3.178	0.002	0.005	0.191	0.003
LOG_S_INTRA_NAT_LI	0.001	-0.168	<.0001	0.006	-0.176	<.0001	0.004	0.206	0.012				0.004	0.198	0.010
LOG_DIST	0.040	-0.304	<.0001	0.002	-0.060	<.0001	0.040	-0.358	<.0001	0.015	-0.211	0.0007	0.048	-0.270	<.0001
LOG_R_GDP_INHAB	0.001	0.072	<.0001	0.003	0.108	<.0001									
LOG_R_GDP	0.002	-0.111	<.0001												

	S3: Japan			S4: Northern & Central Europe			S5: Ukraine & Korea			S6: Belgium France & Italy			S7: North America		
R^2			0.74			0.43			0.71			0.54			0.49
Pr > F			<.0001			<.0001			<.0001			<.0001			<.0001
nber of observations			187			3,129			35			1,044			4,367
Parameters*	PARTIAL R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F	PARTIA L R^2	Estim. Param	Pr > F	PARTIA L R^2	Estim. Param	Pr > F	PARTIAL R^2	Estim. Param	Pr > F
LOG_O_POPULATION_URB	0.006		0.0060	0.010		<.0001	0.207		0.0054	0.068		<.0001	0.002		<.0001
LOG_O_INTRA_URB_LINKS	0.453		<.0001	0.147		<.0001				0.175		<.0001	0.264		<.0001
LOG_O_NATIONAL_GDP				0.009		<.0001				0.003		0.007			
LOG_O_NATIONAL_GDP/INHAB													0.003		<.0001
LOG_O_INTRA_NAT_LINKS				0.001		<.0001				0.007		<.0001	0.002		<.0001
LOG_S_POPULATION_URB	0.023		0.0002	0.106		<.0001				0.042		<.0001	0.006		<.0001
LOG_S_INTRA_URB_LINKS	0.168		<.0001	0.028		<.0001	0.240		0.0001	0.147		<.0001	0.182		<.0001
LOG_S_NATIONAL_GDP			0.0002			<.0001							0.001		0.0130
LOG_S_NATIONAL_GDP/INHAB	0.022														
LOG_S_INTRA_NAT_LI				0.004		0.0056	0.107		0.0022				0.003		<.0001
LOG_DIST	0.060		<.0001	0.127		<.0001				0.094		<.0001	0.015		<.0001
LOG_R_GDP_INHAB													0.001		0.006
LOG_R_GDP							0.146		0.01						

Only estimated values with Pr > F below 5% are indicated

Table VI: Gravitation model of the MNF ownership flows between cities with 8 Spin Glass classes (Negative binomial regression. Number of observations 24,769)

Parameter°	Owner Class	Subsidiary Class	Estimated value	Standard Error	Wald confidence Interval at 95%		Khi2 of Wald	Pr > Khi-2
O_POPULATION_URB			0.0000	0.0000	0.0000	0.0000	2514.24	<.0001
O_INTRA_URB_LINKS			0.0000	0.0000	0.0000	0.0000	492.63	<.0001
O_NATIONAL_GDP			0.0000	0.0000	0.0000	0.0000	6.61	0.0127
O_NATIONAL_GDP/INHAB			0.0000	0.0000	0.0000	0.0000	92.02	<.0001
O_INTRA_NAT_LINKS			-1.0106	0.0009	-0.0123	-0.0089	148.76	<.0001
S_POPULATION_URB			0.0000	0.0000	0.0000	0.0000	1696.52	<.0001
S_INTRA_URB_LINKS			0.0000	0.0000	0.0000	0.0000	393.20	<.0001
S_NATIONAL_GDP			0.0000	0.0000	0.0000	0.0000	29.76	<.0001
S_NATIONAL_GDP/INHAB			0.0000	0.0000	0.0000	0.0000	433.28	<.0001
S_INTRA_NAT_LI								
DIST			-0.0001	0.0000	0.0000	-0.0001	157.42	<.0001
R_GDP_INHAB			-0.0180	0.0017	-0.0212	-0.0148	118.97	<.0001
R_GDP			-0.0002	0.0001	-0.0004	0.0000	4.74	0.0295
O_CLASS * S_CLASS	0	0	2.2881	0.1315	2.0304	2.5459	302.81	<.0001
O_CLASS * S_CLASS	0	1	1.0264	0.341	0.358	1.6948	9.06	0.0026
O_CLASS * S_CLASS	0	3	-1.1143	0.4687	-2.033	-0.1956	5.65	0.0174
O_CLASS * S_CLASS	0	4	0.9812	0.1339	0.7187	1.2437	53.69	<.0001
O_CLASS * S_CLASS	0	5	1.4389	0.4325	0.5912	2.2866	11.07	0.0009
O_CLASS * S_CLASS	0	6	0.9401	0.1631	0.6205	1.2597	33.24	<.0001
O_CLASS * S_CLASS	1	1	3.8885	0.4816	2.9445	4.8325	65.18	<.0001
O_CLASS * S_CLASS	1	5	1.7642	0.7756	0.2441	3.2843	5.17	0.0229
O_CLASS * S_CLASS	2	2	0.6052	0.0807	0.447	0.7635	56.19	<.0001
O_CLASS * S_CLASS	2	7	2.0832	0.1515	1.7862	2.3802	188.99	<.0001
O_CLASS * S_CLASS	3	0	0.4157	0.2089	0.0063	0.8251	3.96	0.0466
O_CLASS * S_CLASS	3	1	0.8368	0.3571	0.1368	1.5368	5.49	0.0191
O_CLASS * S_CLASS	3	7	1.8724	0.2327	1.4163	2.3285	64.74	<.0001
O_CLASS * S_CLASS	3	3	1.1442	0.1594	0.8319	1.4566	51.55	<.0001
O_CLASS * S_CLASS	4	0	0.4298	0.0891	0.2552	0.6044	23.28	<.0001
O_CLASS * S_CLASS	4	1	0.5485	0.1649	0.2252	0.8717	11.06	0.0009
O_CLASS * S_CLASS	4	2	-0.1906	0.0759	-0.3394	-0.0419	6.31	0.012
O_CLASS * S_CLASS	4	4	0.9720	0.0658	0.843	1.1010	217.97	<.0001
O_CLASS * S_CLASS	4	5	0.7311	0.2034	0.3325	1.1297	12.92	0.0003
O_CLASS * S_CLASS	4	6	0.2535	0.0882	0.0805	0.4265	8.25	0.0041
O_CLASS * S_CLASS	4	7	1.8584	0.1312	1.6012	2.1155	200.60	<.0001
O_CLASS * S_CLASS	5	5	5.5427	0.4053	4.7484	6.3370	187.04	<.0001
O_CLASS * S_CLASS	5	7	1.8773	0.7901	0.3286	3.4259	5.64	0.0175
O_CLASS * S_CLASS	6	0	0.624	0.1137	0.4012	0.8468	30.14	<.0001
O_CLASS * S_CLASS	6	1	0.5224	0.2134	0.1041	0.9407	5.99	0.0144
O_CLASS * S_CLASS	6	4	0.5476	0.0871	0.3768	0.7184	39.48	<.0001
O_CLASS * S_CLASS	6	6	1.5548	0.0962	1.3661	1.7434	260.96	<.0001
O_CLASS * S_CLASS	6	7	1.6641	0.1484	1.3733	1.9549	125.81	<.0001
O_CLASS * S_CLASS	7	1	1.2617	0.3316	0.6119	1.9116	14.48	<.0001
O_CLASS * S_CLASS	7	2	2.2637	0.1502	1.9663	2.5582	227.09	<.0001
O_CLASS * S_CLASS	7	3	3.4024	0.4625	2.4959	4.3090	54.11	<.0001
O_CLASS * S_CLASS	7	4	1.3069	0.1077	1.0959	1.5180	147.28	<.0001
O_CLASS * S_CLASS	7	5	0.8493	0.4247	0.0169	1.6816	4.00	0.0455
O_CLASS * S_CLASS	7	6	1.3480	0.1413	1.0711	1.6250	91.01	<.0001
O_CLASS * S_CLASS	7	7	2.288	0.1315	2.0304	2.5459	302.81	<.0001

Only estimated values with Pr > F below 5% are indicated and only significant CONTINENT and COUPLES OF CONTINENTS are listed The negative binomial dispersion parameter was estimated by maximum likelihood.

<u>Classes of the Spin Glass clustering:</u> O_S8: Class of the owner city; S_S8: Class of the subsidiary city

S0: Spain, Portugal and South America, S1: Russia, S2: GB and Asia, S3: Japan, S4: Northern and Eastern Europe, S5: Ukraine and Korea, S6: Belgium, France and Italy, S7: North America