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# At the core of the international financial system[*]

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**Abstract**

This paper offers additional evidence on the structure of the international financial network as emerging from the Coordinated Portfolio Investment Survey (CPIS) dataset collected by the IMF. Making use of blockmodeling techniques which allow us to fit a given community partition to real data, we show that the system is characterized by the presence of a particular type of meso-scale structure known as *core-periphery*, in which a densely connected subset of nodes (core) coexists with a sparsely connected partition (periphery), while the members of the core act as intermediaries between members of the periphery. The composition of the core - whose constituents are identified as the set of systemically-important international financial centers - is rather small and remains stable over time. In addition to very large economies playing host to well-known global financial centers, the core comprises several off-shore financial markets.

*Keywords*: International financial system; intermediation; network analysis

*JEL classification*: F36; G15; E44

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# 1 Introduction

A large volume of empirical literature has shown that the recent evolution of international financial markets has been characterized by three notable features. First, during the last three decades international capital flows across countries have raised at a momentous pace (Lane and Milesi-Ferretti, 2001; 2007), and the interconnectedness of cross-border relationships has grown exponentially (Hattori and Suda, 2007; Hale, 2011). Second, not only the financial flows from rich to poor countries are much lower than predicted by the theory (Lucas, 1990; Prasad *et al.*, 2007), but also the allocation of net capital inflows across developing countries appears somehow puzzling (Gourinchas and Jeanne, 2009). Third, although the growing international financial integration has created substantial opportunities for risk sharing and diversification, the frequency of occurence of banking, currency and debt crises across countries and regions has actually accelerated (Laeven and Valencia, 2008; 2012).

In fact, the global financial turmoil of 2007-09 has dramatically recalled to scholars the need for explicitly considering the issues of systemic stability and functionality, besides those related to volumes and the direction of flows, as guiding principles in the debate on the working and performance of the international financial system. The largely unexpected sequence of panic runs, sudden stops of capital inflows, liquidity black holes and market freezes which has characterized the different stages of the crisis clearly illustrates the role of financial linkages as a channel for the cross-border propagation of shocks. Against this background, it is far from surprising that both academics (Tirole, 2011) and regulators (Haldane, 2009) have come to recognize the usefulness of network theory in mapping the interconnectedness that characterizes the global financial system on the hand, and its importance in understanding the interlinkages and systemic connections among financial institutions, markets and infrastructures to detect and monitor systemic crises on the other one.

From thi point of view, a crucial feature of the international financial network is that a large and highly connected jurisdiction - what is commonly known as a *financial super-market* (Martin and Rey, 2004) - is systemically important either because other countries are financially exposed to it, but also because those same countries rely on it for the continued provision of payment and intermediation services. As recently recalled by the International Monetary Fund (2011), in spite of the dramatic increase of cross-border capital flows registered since the beginning of the 1990s a few "core" advanced countries still dominates the web of linkages across asset classes and regions, both as sources and recipients. One of the key insight of network theory applied to financial stability analysis is that this particular type of topology has the potential of making a network more robust, but it also increases the risk of rare but devastating events. If a highly interconnected country is hit by a large shock, the network might display a tipping-point property and collapse, as the shock is propagated widely via the country‘s large number of links to the rest of the network. It follows that any regulatory attempt at strengthening the governance and the resilience of the international financial system must preliminary go through a proper identification of systemically-important nodes.

In this paper we apply estimation techniques aimed at detecting community structures in networks to a dataset reporting cross-border portfolio holdings of financial instruments. The basic idea - originally developed in social network analysis, and recently refined in the literature exploring the topology of interbank markets - consists in fitting to the data a model in which vertices are organized in clusters, with many edges joining vertices of the same cluster and comparatively few edges joining vertices of different clusters.

We find that a core-periphery partition - in which we single out a relatively small cluster (*core*) with bidirectional links between its components, and a relatively large cluster (*periphery*) whose components are uni-directionally linked to core agents - returns a good fit to the data. The identified core of global financial centers shows a high degree of persistence over the decade 2001-2011, consisting of roughly 30% of all reporting countries. As we restrict the core to countries operating not just as main source or final destination of investments but also as intermediaries, the fraction of systemically important countries shrinks to 20% of the total. Finally, when we consider the intensity of the edges connecting nodes in addition to the mere presence of a link, the *real* core of the international financial system is composed of just 8 to 10 countries (depending on the year of observation). In line with the interest aroused around them in the last few years, three members of the core are Euro-based offshore financial centers - namely, the Netherlands, Luxembourg and Ireland - while the Cayman Islands enter the top league table in 2011 only.[1]

The remainder of the paper is organized as follows. Section 2 offers a brief discussion on the points of contact of two distinct strands of literature dealing with international finance and network analysis, respectively, aimed at theoretically motivating our empirical exercise. Section 3 presents the different variants of the core-periphery model we use for estimation. Section 4 discusses the dataset, and provides a summary of its key features. Results are presented in Section 5, while Section 6 concludes.

## 2 Theoretical background

The three stylized facts recalled at the beginning of the paper can be made mutually consistent by studying how the endogenous evolution of international capital flows in the presence of financial market imperfections and imperfect substitutability across assets organizes itself into a complex network.[2]

As discussed in Matsuyama (2004), domestic borrowing contraints are sufficient to explain the emergence of a polarization between rich and poor countries as the integration of financial markets increases. In a model where countries are inherently identical ex-ante, a progressive integration of financial markets

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[1] The list list of offshore financial centers maintained by the IMF in its Assessment Program can be consulted at http://www.imf.org/external/NP/ofca/OFCA.aspx.

[2] The attribute of complexity is referred to a network which is neither regular nor purely random.

modifies the balance between the equalizing force of diminishing returns to capital and the unequalizing force of wealth-dependent borrowing contraints, and it induces a symmetry-breaking of the steady state with borrowing contraints binding in poor countries but not in rich ones. In turn, by combining the assumptions of risk-averse security issuers and imperfect substitutability of assets one can generate mutually reinforcing demand and size effects, so that assets with a larger demand command a higher price, larger financial areas enjoy better risk diversification, and bilateral gross capital flows depend positively on the absolute size of economies and the decrease of transaction costs as financial globalization progresses (Martin and Rey, 2000; 2004).[3] The predictions from this body of theories are largely consistent with recent empirical evidence on gross cross-border transactions in financial assets obtained by exploiting a *gravity* approach (Claessens *et al.*, 2002; Portes and Rey, 2005), according to which bilateral flows are a function of the economic masses of the origin and the destination country, as well as the geographical distance (here, a proxy of information costs) between them.

A complementary way to look at the question consists in explicitly recognizing, in addition to volumes and market shares, the importance of interconnectedness and patterns of cross-location positions and to analyze the structure and evolution of the complex set of international financial linkages by recurring to network theory (Jackson, 2008; Newman, 2010).[4] From this point of view, the good fit to the data of gravity-type equations suggests that the topological dynamics of the international financial system is governed by a reinforcing mechanism similar to *preferential attachment* (Barabàsi and Albert, 1999): the likelihood to activate a new financial flow (edge) towards a given country (node) is higher, the higher is the number of in-flows already activated towards it, while such a number in turn affects positively the size and deepness - hence, the attractiveness - of its domestic financial market. The signatures of preferential attachment is the emergence of a highly skewed degree distribution (where the degree of a node is the number of outgoing/incoming links) and the absence of assortativity mixing (assortativity is a situation in which nodes prefer links to other nodes with similar degree).[5] In fact, both skewed degree distributions and disassortativity turn out to be pervasive features of financial networks (Soramäki *et al.*, 2006; Iori *et al.*, 2008; Chinazzi *et al.*, 2013).

The network architecture of the international financial system plays a key role in determining its vulnerability to systemic crises. The tendency to increase concentration due to preferential attachment generates a tradeoff between efficiency - since all participants gain in dealing with a financial super-market which exploits specialization and economies of scale and scope - and fragility, as the potential disruption of a central node is immediately transmitted to all its numerous counterparts. There is a broad consensus that not only the size of the U.S. financial market, which represented the epicenter of the 2007-09 global

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[3] All these trends are further strengthed as one adds to the picture the issue of the global safe asset shortage discussed in Caballero (2006) and Bernanke *et al.* (2011).

[4] For a survey of applications of network theory to finance see Allen and Babus (2009).

[5] At least for scale free networks with relatively small scale exponents (Fricke *et al.*, 2013).

financial crisis, but also its central role as investment destination represent key factors in explaining the spreading of the contagion (Claessens *et al.*, 2010).

While the role that agglomeration and specialization forces play in adding a spatial dimension to the analysis of the international financial system has been recognized since the pioneering study on the formation of financial centers by Kindleberger (1974),[6] the theoretical literature on the determinants of international capital flows - as well as its empirical counterpart rooted in the gravity framework - is primarily focused on the original source and the final destination of cross-border capital investments. This leaves out an important feature of cross-border investment patterns, namely that nodes of the international financial network are sistemically important not only if they are the origin or the destination of large volumes of financial activity, but also if they act as an intermediary for other nodes which partecipate in the network only via these top-tier vertices. This is obviously the case for large onshore national financial markets comprising global banking and stock exchange centers, like New York, London or Tokio. But it holds true also for a stream of much smaller offshore financial centers - usually defined as jurisdictions that provide financial services to nonresidents on a scale that is incommensurate with the size and the financing of their domestic economy (Zoromè, 2007) - which in the last years have sensibly grown in importance (Rose and Spiegel, 2007; Lane and Milesi-Ferretti, 2010). Given their importance across several lines of production of financial services - including international banking, insurance, collective investment schemes, asset management, trusts and structured finance - they act as a significant counterpart in the international investment positions of many countries. Their *hub* position in the global financial system makes them effective vehicles for the contagion of regional financial crises to the whole international system. Using expressions that have recently become common in the context of macro-prudential regulatory policy, in order to ensure the stability of the international financial system it is important to identify not only the national markets wich are *too-big-to-fail*, but also those that are *too-interconnected-to-fail*.

A natural approach to isolate the nodes of the international financial web deemed to be systemically important along the two dimensions just identified - i.e., size and intermediation - consists in selecting them according to the position they occupy inside the network. Previous work has addressed this issue by recurring to node-specific statistics, such as measures of centrality,[7] node strength[8] and prestige[9] (von Peter, 2007; Cetorelli and Peristiani, 2013; Chinazzi *et al.*, 2013), or distinguishing between countries reporting and non reporting statistics to the data collectors (Minoiu and Reyes, 2013). In this paper we fit a core-periphery structure to data on bilateral cross-border portfolio asset hold-

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[6] For a survey on the literature on international financial centers exploring the intersections between economics and geography see Tschoegl (2000).

[7] Centrality can be alternatively measured by the number of links terminating upon a node (*in degree*), by the distance from other nodes (*closeness*), or by assessing the degree by which a node lies on the shortest path between any two other nodes (*betweenness*).

[8] Node strength is the total value of flows originating or terminating in a given node.

[9] The prestige index measures the importance of a node by taking into account the importance of its neighbors.

ings by recurring to blockmodeling techniques, along the lines first proposed by Borgatti and Everett (1999). Identifying intermediate-scale structures in an andogenous way is an important aspect in the analysis of complex networks (Fortunato, 2010), as they allow to discover features that are not evident either at the global level of aggregate statistics or at the local scale of nodes and edges. In particular, the idea is to partition the network of national financial markets into a densely connected core and a sparsely connected periphery, by testing the additional assumption that countries in the core are well-connected to those in the periphery while the opposite does not hold true. The components of the core are thus central to the network, either because they are densily interconnected and because they are on the shortest paths linking other nodes. The identification of such critical players in the international web of exposures has crucial implications for macro-prudential surveillance, and hence for financial stability.

## 3 Defining a core-periphery structure

A network consists of a set of nodes that are connected by links. It can be defined as a graph $(N, g)$ where $N = [1, \ldots, n]$ is the set of nodes and $g$ is a square matrix of dimension $n \times n$ referred to as *adjacency matrix*. The component $g_{ij} \in \{0, 1\}$ represents the availability of an edge from node $i$ to node $j$. The edge weight $g_{ij} \geq 0$ can also take on non-binary values, representing the strength of the relationship, in which case we refer to $(N,g)$ as a *weighted* (or valued) graph. Finally, the graph is *directed* if it is possible that $g_{ij} \neq g_{ji}$, and *undirected* if $g_{ij} = g_{ji}$ for all $i, j \in N$.

The classification and the measurement of the properties of a network are in general obtained by a combination of aggregate summary statistics (e.g., density, asymmetry), node-specific statistics (e.g., degree, centrality) and the identification of latent intermediate-scale *meso*-structures (e.g., communities, clusters). In this paper we focus on the latter dimension.

In particolar, the approach known as blockmodeling (Doreian *et al.*, 2005) consists in reducing a large, potentially incoherent network into a comprehensible structure by rearraging the columns and rows of the original adjacency matrix. The final goal is that of obtaining classes of units - also known as *clusters* - that share the same connection pattern to other units. A *community structure* is defined as a partition of the set of nodes $N$ into $\kappa$ clusters, $\mathbb{C} = \{C_1, ..., C_\kappa\}$, such that each node belongs to one cluster only. Thus, each partition determines an equivalence relation, and vice-versa. The selection of a proper partition of units in terms of a chosen equivalence type corresponds to an optimization problem $(\Phi, P)$, whose solution determines the clustering $\mathbb{C}^* \in \Phi$ for which

$$P\left(\mathbb{C}^*\right) = \min_{\mathbb{C} \in \Phi} P\left(\mathbb{C}\right), \tag{1}$$

where $\Phi$ is the set of feasible clusterings and $P$ is a criterion function to be minimized. Several criterion functions have been proposed in the literature, expressed either in terms of a dissimilarity measure between pairs of units, or as a function measuring the fit of a clustering structure to an ideal one.

In what follows we set $\kappa = 2$, and we look for partitions in which the members of one community - called *core* - are bilaterally linked with each other, while the members of the remaining community - called *periphery* - are minimally (ideally, none at all) interconnected.

### 3.1 The discrete model

The discrete approach proposed by Borgatti and Everett (1999) compares a real network to an ideal block model made up of a fully connected core and a periphery that has no internal edges but is fully connected to the core. As we consider binary adjacency matrices, the idealized core-periphery structure is therefore given by the model $\mathbf{M}_{BE}$:[10]

$$\mathbf{M}_{BE} = \begin{pmatrix} \mathbf{CC} & \mathbf{CP} \\ \mathbf{PC} & \mathbf{PP} \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{CP} \\ \mathbf{PC} & \mathbf{0} \end{pmatrix} \tag{2}$$

where **1** and **0** denotes submatrices of ones and zeros respectively (i.e., the core and the periphery of the network), while none restriction is imposed on the off-diagonal blocks **PC** and **CP**.

The estimation procedure starts by sorting the binary counterpart of the real adjacency matrix, so that the (unknown) target core nodes are ordered first. Let a candidate core $C$ be composed of $n_c < n$ members, $C = \{1, ..., n_c\}$ . Then one can measure the fit of the corresponding core-periphery structure by counting the inconsistencies between the observed network and the ideal model $\mathbf{M}_{BE}$ of the same dimension, and aggregating over the blocks. The matrix containing the aggregate errors in the individual blocks is given by:

$$E(C) = \begin{pmatrix} E_{\mathbf{CC}} & E_{\mathbf{CP}} \\ E_{\mathbf{PC}} & E_{\mathbf{PP}} \end{pmatrix} = \begin{pmatrix} n_c(n_c-1) - \sum_{i,j \in C} g_{ij} & 0 \\ 0 & \sum_{i,j \notin C} g_{ij} \end{pmatrix} \tag{3}$$

while the total error score $e$, obtained by aggregating the errors across the four blocks, is normalized by the total number of edges in the real network:

$$e(C) = \frac{E_{\mathbf{CC}} + E_{\mathbf{CP}} + E_{\mathbf{PC}} + E_{\mathbf{PP}}}{\sum_i \sum_j n_{ij}} = \frac{E_{\mathbf{CC}} + E_{\mathbf{PP}}}{\sum_i \sum_j n_{ij}}. \tag{4}$$

Notice that the normalized total error score is a function of $C$, given that every possibile partition produces a particular error. Hence, the optimal partition $C^*$ minimizing the total error score is calculated by means of a combinatorial algorithm such that:[11]

$$C^* = \arg\min e(C) = \{C \in \Omega | e(C) \, \forall C \in \Omega\}, \tag{5}$$

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[10] Since the newtork is not self-referential, in what follows diagonal elements will be ignored.

[11] The combinatorial optimazion exercise for detecting a discrete core/periphery structure has been based on a genetic algorithm, see Borgatti and Everett (1999, pag.381).

where $\Omega$ denotes all strict and non-empty subsets of the population $\{1, ..., n\}$.

This model can also be used for partitioning weighted graphs, that is without recurring to a preliminary transformation of the real adjacency matrix in its binary counterpart. In this case, the procedure consists in maximizing the correlation between the binary ideal model $\mathbf{M}_{BE}$ and the weighted observed data, and it is equivalent to running a $t$-test for the difference in means between the core-to-core correspondence and the periphery-to-periphery correspondence, respectively. The best core/periphery partition is obtained as the difference in means across blocks, relative to the variation within blocks, is maximized.

## 3.2 Tiering

Craig and von Peter (2010) restrict the discrete core/periphery partitioning proposed by Borgatti and Everett by imposing to the ideal model the additional requirement that the members of the core must act as intermediaries for the members of the periphery.[12] In other words, core nodes must both lend to and borrow from at least one periphery node, so that this model is nested within the discrete one described above. The network can now be partitioned into a top tier (core) whose members are fully interconnected and intermediates among non-members, and a low tier (periphery) whose members participate to the whole financial market only via the top-tier entities.

A perfect tiering structure is represented in the left panel of Figure 1. The top tier is represented by nodes A, B and C, while the remaining nodes belong to the lower level. Some of the latter can be at the same time borrower and lender (like nodes E and G), provided that their activity is intermediated by a member of the core. In order to exemplify how a real network can produce errors with respect to this benchmark, in the right panel of Figure 1 we remove the links from B to C and from C to H, and add a link from D to H. This generates three separate violations of the ideal partition which are representative of different classes of errors: *i*) one member of the core is not fully connected to all the other core members; *ii*) two periphery nodes are linked directly; *iii*) a core member does not lend to (or borrow from) a periphery node.

From an analytical point of view, the ideal model $M_{CP}$ is now given by:

$$\mathbf{M}_{CP} = \begin{pmatrix} \mathbf{CC} & \mathbf{CP} \\ \mathbf{PC} & \mathbf{PP} \end{pmatrix} = \begin{pmatrix} \mathbf{1} & \mathbf{RR} \\ \mathbf{CR} & \mathbf{0} \end{pmatrix} \tag{6}$$

where $\mathbf{CR}$ is a $(n - n_C) \times n_C$ column-regular matrix and $\mathbf{RR}$ is a $n_C \times (n - n_C)$ row-regular matrix.[13] The aggregate errors in the off-diagonal blocks are equal to:

$$E_{CP} = (n - n_C) \sum_{i \in C} \max \left( 0, 1 - \sum_{j \notin C} g_{ij} \right) \tag{7}$$

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[12] The model has been developed to analyse instances of the German interbank market. Other applications to the Italian and the Dutch cases can be found in Fricke and Lux (2012) and van Lelyveld and in't Veld (2012), respectively.

[13] That is, at least one entry has to be non-zero in each column of $\mathbf{CR}$ and in each row or $\mathbf{RR}$.

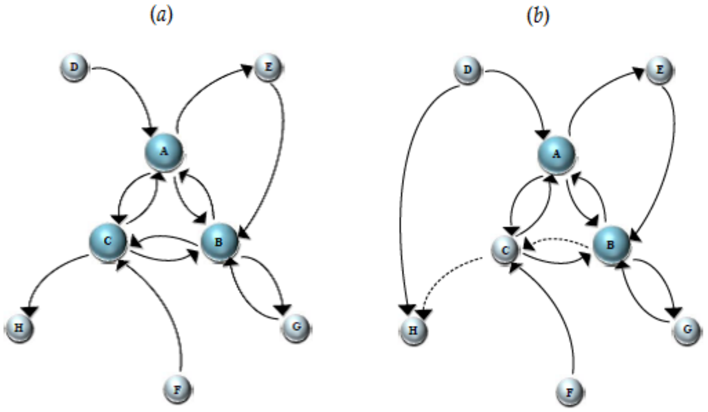

Figure 1: Perfect $(a)$ and imperfect $(b)$ tiering structure.

and

$$E_{PC} = (n - n_C) \sum_{j \in C} \max \left( 0, 1 - \sum_{i \notin C} g_{ij} \right) \tag{8}$$

leading to additional non-zero entries in the total error score (3). Once again, the optimal core is calculated by minimizing the number of errors by means of a combinatorial optimization algorithm.

## 4 Data description

The procedures aimed at detecting a core-periphery meso-structure presented in the previous section are applied to a weighted-directed graph describing the international financial system. Nodes are represented by national financial markets, while edges are the direct cross-border asset and liability positions linking the issuing country to the holding one. Thus, an outgoing link starts from a country issuing a security (whether it refers to debt or equity) and reaches the country where the entity that holds it resides. The data source is the Coordinated Portfolio Investment Survey (CPIS) collected by the IMF.[14] The CPIS dataset, which spans over the time period 2001-2011, reports end-year cross-border portfolio holdings of equity securities, long-term debt securities and short-term debt securities listed by country of residence of the issuer. As discussed in Obstfeld (2012), gross international asset and liabilities positions are key in assessing the scope and deepness of the transmission and amplification of shocks between countries.

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[14] The data can be retrieved at http://cpis.imf.org/.

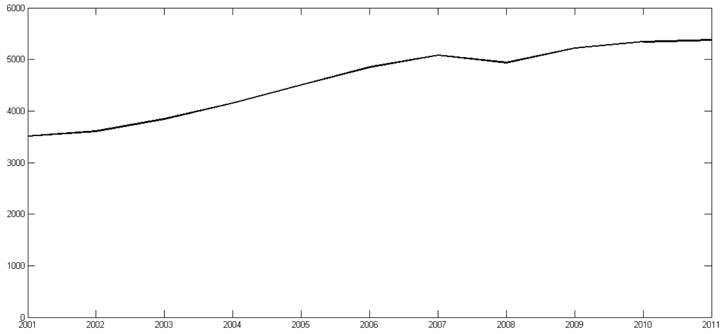

Figure 2: Number of active links over time.

The international financial network is invariably composed of a total of 237 nodes, while each year complete bilateral data are available for about 70 countries.[15] The degree of interconnectedness has increased sensibly over time, as shown in Figure 2 where we plot the number of active links among nodes. The network remains very sparse over the time horizon, however, given that the degree of connectivity - measured as the fraction of actual to possible links - ranges from 0.066 in 2001 to 0.092 in 2011.

The general network properties of this dataset has been extensively explored by Chinazzi *et al.* (2013), who provide results from a battery of aggregate and node-specific statistics.[16] They find that the network is asymmetric, with a right-skewed bimodal node-degree distribution, and that both the average nearest-neighbor (ANN) degree and the average binary clustering coefficients have tended to increase over the last decade, with the exception of 2008. The correlation between node degree and node strength is in general large and positive, while the correlations beetween node degree/strength and node ANNdegree/ANNstrength are low and negative. Hence the international financial network is disassortative, i.e. high-degree nodes have a high probability to be connected with low-degree nodes. When just binary adiacency matrices are considered, the correlation between the degree and clustering coefficients is on average large and negative; for valued networks the sign of the correlation is reversed, so that countries which hold/issue a large volume of securities tend to interact with pairs of countries which are themselves very interconnected. While the authors claim that such a rich-club behavior is consistent with a core-periphery structure, they do not perform any algorithmic-based blockmodeling investigation to corroborate their assumption. The next Section of the

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[15] Each year a certain number of nodes are isolated. We retain them in the network if they contribute with a positive entry to the total adjacency matrix in at least one of the years under scrutiny. This allows us to take into account the evolution over time of international financial integration, and it facilitates intertemporal comparisons.

[16] Their analysis covers the time span 2001-2010.

paper is devoted to fill this gap.

# 5 Results

The different blockmodeling procedures discussed in Section 3 are applied sequentially, moving from the discrete to the tiering model - both of them estimated by means of binary adjacency matrices - and ending with estimates of the discrete model with valued matrices. This allows us to operate a series of refinements of the core and to progressively restrict its composition, eventually arriving to robustly identify the systemically-important nodes of the international financial network.

We begin by comparing the relative core sizes obtained by fitting the discrete and the tiering models to the annual binary adjacency matrices associated to the real data. Results are presented in Figure 3. In both cases the core increases very slowly over time, and it amounts on average to 31% and to 21% of the nodes, respectively.[17] Since the tiering model implies that core members act as intermediaries, while the same is not necessarily true for the discrete one, the relative size of the core calculated with the former model is sistematically smaller, and with the exception of few borderline cases its components represent a proper subset of the set of countries comprised in the discrete core. A comparison between the expansion of cross-border financial relationships - the number of active links grew at an average annual growth rate of 5.1% from 2001 to 2011 (cf. Figure 2) - and the much slower pace of growth of the network core - comparable figures for the discrete and the tiering core sizes are 1% and 1,6%, respectively - confirms that the bulk of financial activity has tended to remain concentrated in a relatively small number of global centers in spite of the large increase in the degree of integration of the world capital markets recently occured.

As expected, the density of the core partition in the tiering model is sensibly higher than in dicrete case, as reported in Figure 4. In both cases, the values are very stable over time. In particular, the global crises of 2007-09 seems to have brought no substantial change in the structure of intermediation in the international financial system.

In order to gain additional insights on the composition of the network structure, we compute the fractions of intermediaries, pure original sources and pure final destinations of financial securities issued over time. Here we define pure original sources as countries with a positive out-degree and a zero in-degree in a given year, whereas the reverse holds for pure final destinations. The remaining countries, with both positive in- and out-degree, are intermediaries. Finally, if in one period a country has no links it is defined as isolated. Results for the core and the periphery partitions obtained with the discrete model are presented in Figure 5. We find that the fraction of intermediaries in the core is highest (this fraction is equal to 1 in the tiering model), while the majority of countries in

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[17] In absolute terms, the average number of core components are 66 and 44 for the discrete and the tiering models, respectively.

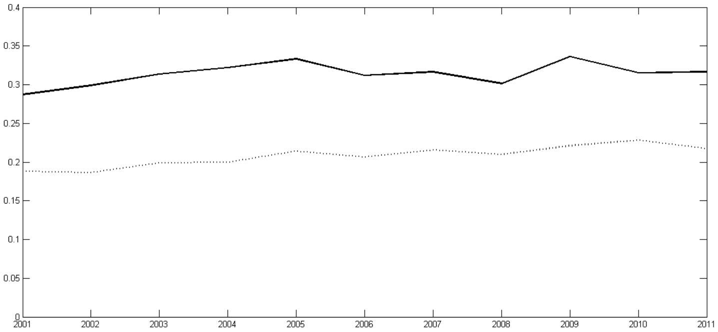

Figure 3: Relative core size over time for the discrete (solid line) and the tiering (dashed line) models.

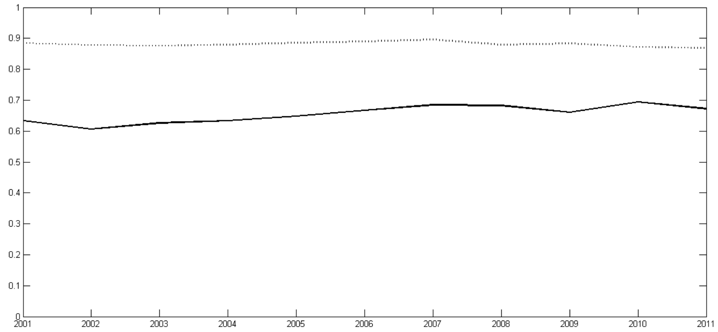

Figure 4: Density of the core block over time for the discrete (solid line) and the tiering (dashed line) models.

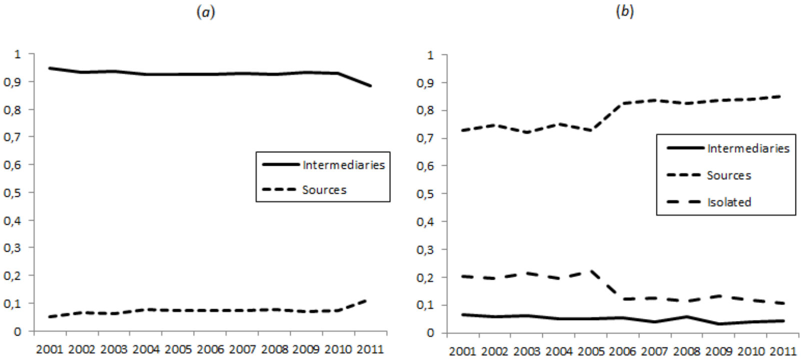

Figure 5: Structure of the core and the periphery in the discrete model. Fractions of intermediaries, pure original sources and isolated nodes in the core (Panel *a*) and the periphery (Panel *b*), respectively.

the periphery acts as pure originators of securities. Interestingly enough, none country results to be a pure final destination. The fraction of countries in the periphery which are pure issuers of financial securities, in particular, has increased over time, a pattern matched by a specular decrease in the fraction of countries which both originate and receive funds. Given that the periphery is composed solely by emerging markets, this piece of evidence suggests that the Lucas paradox - i.e., that capital flows from poor to rich countries rather than in the opposite direction - has become even more baffling over the last decade.

An additional issue worth exploring is the stability of the link structure in the different blocks. This allows us to assess whether subsequent occurrences of the network share many common links. This is done by employing the so-called Jaccard index, defined as:

$$J = \frac{M_{11}}{M_{01} + M_{10} + M_{11}} \tag{9}$$

where $M_{11}$ is the number of links present in two consecutive periods $t$-1 and $t$, $M_{01}$ the number of newly created links in $t$, and $M_{10}$ the number of links present in $t$-1 but severed in $t$. The Jaccard index measures links which survive as a fraction of links which are established at any of the two points in time, and it also takes into account those issuers/holders which are active in only one of the two periods. Social networks are usually considered to be sufficiently stable when $J$ is larger than 0.3 (Snijders *et al.*, 2010).

Figure 6 reports the evolution over time of the indicator for the four blocks separately.[18] The Jaccard index signals that system of micro-level bilateral connections in the PC and the CC blocks is stable (with average values equal to

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[18] For ease of exposition,we present results for the tiering model only. The stability of the link structure for the discrete model is qualitatively similar.

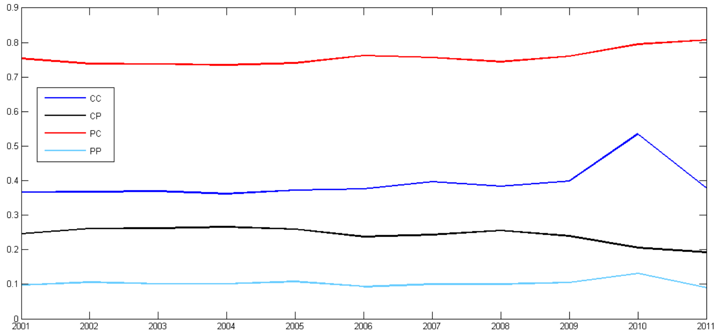

Figure 6: Jaccard Index for the CC, CP, PC and PP blocks over time.

0.76 and 0.39, respectively), while the relationships in the two remaining blocks are rather volatile. As we focus on the issue of how funds are intermediated, our calculations suggest that periphery countries tend to issue securities towards preferred partners among the core of financial centers, while funds flowing from the center to the periphery change destinations quite frequently.

The relative total error scores calculated over the time horizon for the discrete (solid line) and the tiering (dashed line) models are shown in Figure 7. In both cases, the values are well below unity, signalling that the core/periphery partition provides a better description of the data than an alternative structure consisting of just a periphery.[19] We first note that the fit for the tiering model is extremely good in absolute terms, sensibly better that the discrete one, and it remains constant over the whole period. Second, the fit for the discrete model improves with time, indicating that the tendency to a polarization of national financial markets in a core of strongly interconnected global centers and a sparse periphery has incresed all over the last decade.

To assess the statistical significance of the error scores obtained by fitting the core/periphery structure to the data, we set up a simple testing procedure based on the definition of a null model. The latter is obtained by generating a large number of random instances of a given network structure. The same fitting model employed with real data is then applied to simulated data, so that the distribution function of the errors under the null can be used to calculate the probability of obtaining by chance a value equal or higher of a given threshold, under the conditions specified by the null itself. If the error scores of the core/periphery fit applied to real data are below such a percentage boundary, one can exclude with a significance level equal to the inverse of that percentage that the results from the estimation procedure are spuriously obtained from a network structure with the same characteristics of the null.

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[19] Recall that the total error score should not be interpreted as a percentage, given that an error can occur either because of the absence of a link where the link is expected to exist, and because of the presence of a link where the latter ought to be absent.

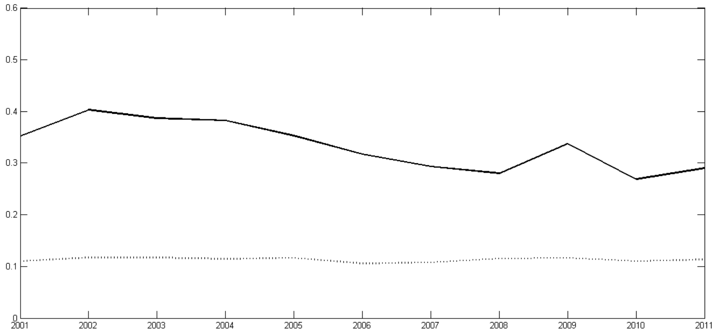

Figure 7: Error scores in the discrete (solid line) and the tiering (dashed line) models.

In particular, we calculate the distribution functions of the total error scores obtained by fitting the tiering model to 1000 replications of two typical networks, whose sample size and density are set equal to the correspondent average values observed in the data. Following a choice that is becoming a standard in the literature,[20] the two null models we consider are:

- An Erdös-Rényi random graph model, with a probability of forming a link $p = 0.08$. Notice that under such a null we do not expect to observe a core/periphery structure, so that the total error scores one obtains by fitting an ideal core/periphery partition to simulated data should be relatively high.
- A scale-free random graph model, generated according to the preferential attachment approach of Barabàsi and Albert (1999). The network structure that emerges under such a scheme has a degree distribution that follows a power law, with few highly connected nodes and a large number of nodes with few links.

As shown in Figure 8, where for ease of comparison we report also the results obtained by fitting to the real data the discrete model, we can significantly reject the hypothesis that the particular sets of identified cores and peripheries could be an artifact of applying the core/periphery estimation methodology either to random data, or to a system governed by a pure preferential attachment mechanism. In other words, intermediation turns out to be a key feature in identifying systemically-important international financial centers.

So far, we have applied the discrete and the tiering models to the binary adjacency matrices associated to yearly data. This has allowed us to represent the structure of the international financial system by focussing on the presence of

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[20] See e.g. Craig and von Peter (2010) and Fricke and Lux (2012).

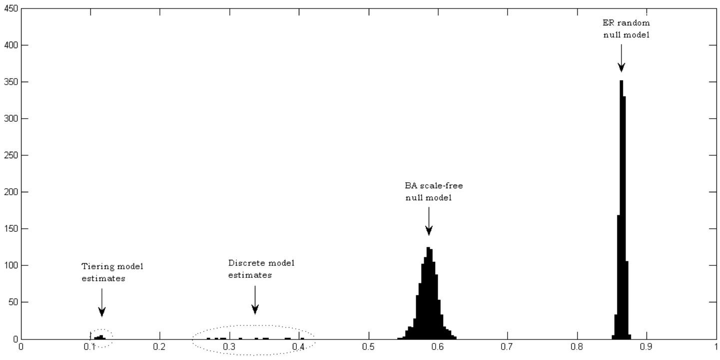


Figure 8: Empirical distribution functions of total error scores for the discrete model, the tiering model, 1000 scale-free networks (BA) and 1000 random networks (ER).

linkages among national financial markets. As mentioned in Section 3, however, the discrete model can also handle valued data, the estimation algorithm being assimilated in this case to a difference in means $t$-statistic procedure. The core size that results is sensibly smaller the the one obtained with binary data, and its composition is rather stable over time. The list of countries in this restricted core are reported, for each year under investigation, in Table 1.

Table 1: Core members.

| 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 |
|---|---|---|---|---|---|---|---|---|---|---|
| CAN | FRA | FRA | FRA | CAN | FRA | CAN | FRA | FRA | CAN | CAN |
| FRA | DEU | DEU | DEU | FRA | DEU | FRA | DEU | DEU | FRA | CYM |
| DEU | ITA | IRL | IRL | DEU | IRL | DEU | IRL | IRL | DEU | FRA |
| ITA | JPN | ITA | ITA | IRL | ITA | IRL | ITA | ITA | IRL | DEU |
| JPN | LUX | JPN | JPN | ITA | JPN | ITA | JPN | JPN | JPN | IRL |
| LUX | NLD | LUX | LUX | JPN | LUX | JPN | LUX | LUX | LUX | JPN |
| NLD | GBR | NLD | NLD | LUX | NLD | LUX | NLD | NLD | NLD | LUX |
| GBR | USA | GBR | GBR | NLD | GBR | NLD | GBR | GBR | GBR | NLD |
| USA |  | USA | USA | GBR | USA | GBR | USA | USA | USA | GBR |
|  |  |  |  | USA |  | USA |  |  |  | USA |

The relative error score of the core partition is always zero, indicating that the fit of the model when the valued adjacency matrices are considered is almost perfect. Interestingly enough, the estimated core does not contain several national financial markets hosting top global financial centers according to the Global Financial Centres Index ranking (Yeandle *et al.*, 2013), like Hong Kong, Singapore and Switzerland.

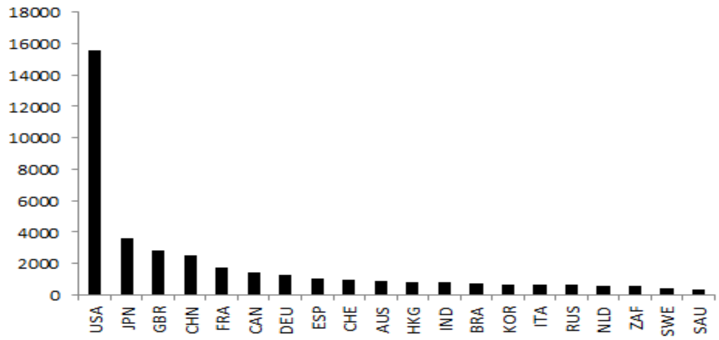


Figure 9: Market capitalization of top twenty global stock markets, 2001-11 average, in billion US dollars. Source: World Development Indicators, World Bank.

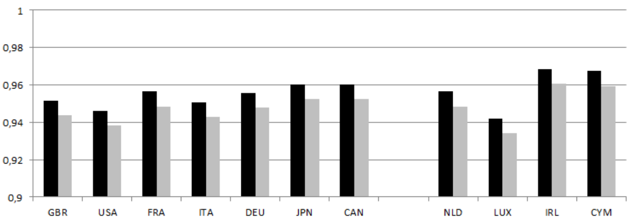
A comparison between the list of countries we identify as the strict core of the international financial system and the list of the top twenty global capital stock markets can be made by looking at the graph in Figure 9, where we report the 2001-11 average market capitalization of listed companies, in billions of US dollars.

This allows us to observe that the set of systemically-important nodes is composed of two distinct groups of national financial markets:

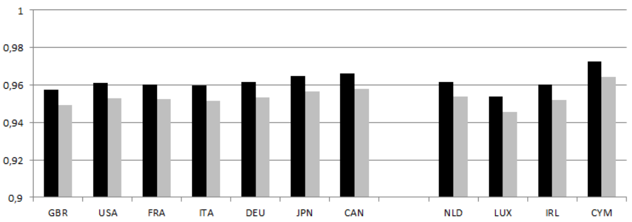
1. Members of the G7 group of the most industrialized countries that host a globally relevant stock exchange, like the USA, Japan, Great Britain, France, Canada and Germany.
2. Off-shore financial centers, which operate as pure intermediaries thanks to a favourable legislation, and in which the size of the capital stock market is somehow limited, if not insignificant at all. In this class we insert the Netherlands, Luxembourg, Ireland and the Cayman Islands.

The only country which does not belong to either group is Italy which, however, in addition to being part of the G7 group has been the issuer of the third largest public debt in the world (behind the USA and Japan) during the period under investigation. Differently to what has been repeatedly argued in the literature on international financial centers (see e.g. Poon *et al.*, 2004), playing host to a major stock exchange does not appear to be a necessary condition for assuming a systemic importance inside the global financial network. Intermediation centers that operate maturity and currency transformation, create liquidity and facilitate intertemporal trade without being necessarily a final destination of international investments are key to the functioning of the international system as well.

(*a*) 2001



(*b*) 2006



(*c*) 2011

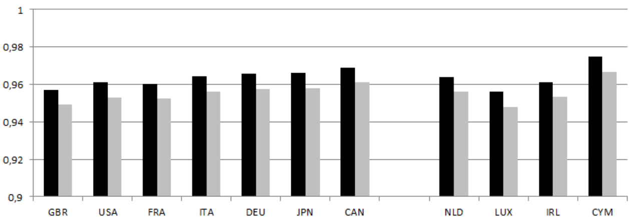


Figure 10: Impact of node removal on network properties, in percentage of the value for the complete real network. Black bars: total density; grey bars: average node degree.

In order to appreciate this point, as a final step we study the impact on the topological properties of the international financial system of the removal of each single core members, by focusing on several selected network statistics. In particular, Figure 10 reports the ratio between the density (black bars) and the average node degree (grey bars) calculated as the node indicated in the horizontal axis is removed, and the ones obtained for the complete network. The distance from the unit value can thus be interpreted as a percentage loss of value transferred and number of transactions in the case of disruption of one core member. The evolution over time of the degree of systemic importance of each single node can be appreciated by replicating the calculations at evenly spaced intervals: (*a*) 2001, (*b*) 2006, (*c*) 2011. To increase the readability of the graphs, we separate the group of on-shore global markets from proper off-shore centers.

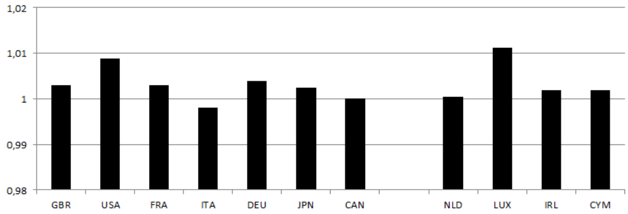
We notice three interesting facts. First, the impact linked to the removal of the nodes identified in the core of the weighted network is in all cases severe, and much higher than the impact generated by the removal of a randomly selected node. In particular, a selected attack to a core node makes the network significantly smaller and even more sparse. The international financial system is therefore vulnerable to the failure of strongly connected financial hubs, and the increase in efficiency coming with the exploitation of scale and scope economies by financial super-markets is accompanied by a strong concentration of risks. Notice that this exercise abstracts completely from phenomena related to spillover and fire-selling externalities and the cascading impact of loss-avoidance behaviors, which are likely to transmit and amplify significantly the original shock through contagion.

Second, the potential negative impact of node removals both in terms of density and in that of interconnectedness has slightly decreased over the decade, however. This finding corroborates previous evidence based on indicators for availability of human resources, business environment, market access, infrastructure, general competitiveness, and assessments by market participants suggesting that during the last decade the increase in financial integration has been accompanied by a fiercer competion to more consolidated global financial supermarkets driven by new regional centers based in emerging economies (Deutsche Bank Research, 2010).

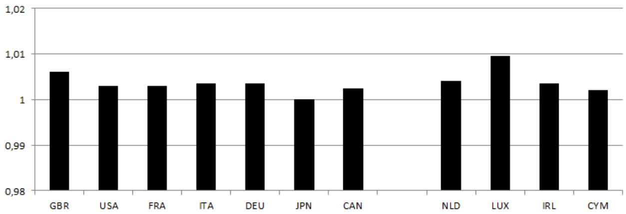
Third, the node which ranks first in terms of systemic importance is Luxembourg, while the impact exerted by the three other off-shore centers in the core is entirely comparable to that of much larger economies. The role of financial centers playing host to a huge number of mutual funds and trusts, securities and derivatives dealers and other financial vehicles operating maturity, liquidity and currency transformation appears to be as crucial as that of large original sources or final destinations in mapping the risks of the international financial system. In line with the current debate on the monitoring and regulation of individual financial institutions, also for national financial markets the too-big principle must be complemented with the too-interconnected one in thinking about the governance of the international financial architecture.

Figure 11 reports values obtained by means of the same node-removal method-

(*a*) 2001



(*b*) 2006



(*c*) 2011

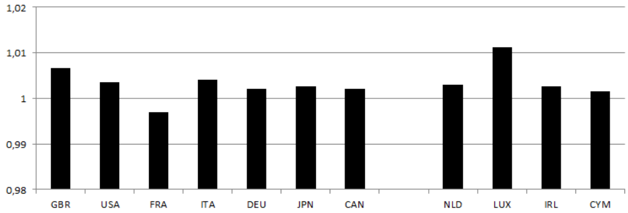


Figure 11: Impact of node removal on network properties, in percentage of the value for the complete network. Bars: relative average shortest path length.

ology for the statistic measuring the average geodesic distance in the network, that is the average length of the shortest path from a given node to each other node reachable from it. The removal of a core node is expected to significantly increase the number of steps necessary for any other node to reach other parts of the network. This is in fact what we find, except for Italy in 2001 and France in 2011. Once again, the most systemically important financial center turns out to be Luxembourg, while the role of the USA as a global center has somehow decreased over the time horizon under investigation in favor of the British financial market.

# 6 Conclusion

The global financial crisis of 2007-09 has brought to light the utility of network theory in analyzing how systemic risk unfolds and propagates across markets and borders, and it led to an explosion of research in the field. In this paper we complement previous studies exploring the topology of the international financial system, by using blockmodeling techniques aimed at endogeously isolating a core-periphery structure. The model partition we fit to the data is based on precise assumptions on the position each node occupies inside the network. Contrary to the focus on large original sources or final destinations of cross-border investments adopted by previous studies, here core countries play a key role because they intermediate between countries in the periphery, and thereby hold together the entire international financial system. As we refine the analysis moving from binary to weighted adjacency matrices, we find that the number of countries comprised in the core is rather small, and it remains stable over the time span 2001-2011. Besides very large economies playing host to well-known global financial centers, corresponding to the G7 group (USA, Great Britain, Germany, France, Japan, Canada and Italy), the core comprises several off-shore financial markets mainly based in the Euro area, like Luxembourg, the Netherlands and Ireland. The Cayman Islands enter the top league table just in 2011.

Since the main purpose of this paper consists in contributing to draw the *global risk map* (Issing and Krahnen, 2009) regulators should have in their pocket, it seems appropriate to suggest three possible ways of reading it or - if seen from a different angle - of extending the analysis offered above in future work. First, the identification of key intermediaries of the international financial network puts into context the need for a macro-prudential approach to promoting global stability avoiding a *one-size-fits-all* perspective, in particular as regards the future role of the IMF as a crisis manager and a crisis lender (Eichengreen, 2009; Obstfeld, 2009). Second, while in this paper we put a special emphasis on the core partition, a comprehensive analysis of the systemic importance of key periphery countries is in order as well. Third, in the debate aimed at balancing the pros and cons of off-shore financial centers (Hines Jr., 2010; Morriss, 2010), the role they play as active intermediaries in the international financial system should be properly taken into account.

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