Interbank Networks and the Benefits of Using Multilayer Structures

Danielle Sandler dos Passos, Helder Coelho, Flávia Mori Sarti

***Abstract*—**Complexity science seeks the understanding of systems adopting diverse theories from various areas. Network analysis has been gaining space and credibility, namely with the biological, social and economic systems. Significant part of the literature focuses only monolayer representations of connections among agents considering one level of their relationships, and excludes other levels of interactions, leading to simplistic results in network analysis. Therefore, this work aims to demonstrate the advantages of the use of multilayer networks for the representation and analysis of networks. For this, we analyzed an interbank network, composed of 42 banks, comparing the centrality measures of the agents (degree and PageRank) resulting from each method (monolayer *x* multilayer). This proved to be the most reliable and efficient the multilayer analysis for the study of the current networks and highlighted JP Morgan and Deutsche Bank as the most important banks of the analyzed network.

***Keywords*—**Complexity, interbank networks, multilayer networks, network analysis.

I. Introduction

COMPLEXITY is a relatively new approach, which seeks the understanding of systems and phenomena through the mixture of theories from areas. In recent years, the use of ideas related to complexity have proliferated among routines that seek to understand collective behaviours in systems that encompass different elements that interconnect in some way and provoke effects at different scales [1], [2]. Among these theories, the analysis of networks has been spreading through several areas due to the possibility of enabling a visual representation for comprehension of numerous complex systems, by capturing topological and structural characteristics of the interconnections between the agents [3].

A complex system is defined as a groups of agents that interact with each other and provide the system with the capacity for constant modification, learning, adaptation and evolution [4]. Moreover, such interactions promote the emergence certain features to the system, which are not present in its components individually [5].

The use of network theory, in various fields - biological, social, economic, etc. – allows the understanding of scenarios that were previously difficult, if not impossible, to represent [6]. In general, the networks are represented by graphs that assume the form

$$G = (V, E) \quad (1)$$

where G is the graph itself, V are the vertices (nodes) representing the agents and E are the edges that seek to delineate the interconnections between the nodes [7], being

$$E \subseteq V \, x \, V \quad (2)$$

However, in spite of its contribution to quantitative analysis of agents within a complex system, the networks analysis may present failures in the aggregation of information of diverse layers of relationships using a single type of connection between the nodes [8], [9], which usually results in a dangerous oversimplification of the real world [10]. Considering that, the vast majority of systems are structured in multilayer relation, the summarizing into a single layer can lead to erroneous results and/or to inability to solve certain problems [11]. In order to avoid this situation, there have been diverse proposals to use complex systems analysis based on multilayer structures [11], also known as multiplex network [12], multilevel [13] or multirelational [14]. In summary, this type of network is structured in several layers that represent different types of aspects or relations between the nodes simultaneously [15], so that each layer ends up resembling a monolayer network [11]. Generally, the nodes appear in the different layers and interconnect with each other through inter-layer edges, which have the function to interconnect the same node in diverse layers.

As a definition, we assume a multilayer network such that

$$G = (V, E_\alpha) : \; E_k \subseteq V \, x \, V \; \forall \; k \in \{1, \dots, \alpha\} \quad (3)$$

where α corresponds to the number of layers the network has [16]. In addition, in multilayer, as well as in monolayers, one of the main mechanisms of analysis is the measurement of some centrality variables, considering that, as already highlighted [17], the centrality of the nodes shows those responsible for the rapid spread of information, failures and other stimuli and assets among agents. In recent studies, there has been widespread use of networks' centrality measurements, applied to several types of analysis: from theoretical investigation of the best designs for network efficiency to the identification of relations among proteins that are essential for cell survival [18]. However, the results

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obtained in studies analyzing separately each layer of a multilayer network – as monolayer networks – or when aggregating the whole information on a single network are misleading, which highlights the urgency in adopting the multilayer representation [17].

It is important to point out that the financial networks focused in this study have complex structures and functions [19]-[21] where banks and other economic agents interrelate simultaneously through various types of activities [22]. Thus, using a monoplex network for its representation may result in discarding several important information which may encompass data for a more coherent and comprehensive analysis of the markets [11]. In addition, in the multilayer analysis, the measures of centrality – such as degree, PageRank and others – are also used to analyse the relationships among agents in the network and its aggregated properties, similarly to the monolayer. However, comparing results from different studies, it is possible to identify inconsistency in the evidences presented. Therefore, we suggest that it would be important to adopt multilayer representations of relationships among agents in networks for investigation of complex networks analysis using systemic approach [9]. Thus, the objective of this work is to investigate the effectiveness of the use of multilayer structures in the analysis of the complex systems related to the network formed by 42 representative banks nowadays, comparing the results obtained in the aggregate (monolayer) and multilayer approaches.

The article is organized in 5 parts, this introduction being the first, encompassing a literature survey of the subject and objectives of the investigation. The following part is a more detailed discussion of the results and data used in the analysis, and the third section includes the discussion of the findings in comparison to the scope of the topic. Next, we present the methodology used and lastly, the bibliographic references are highlighted.

II. Results

Observing the network composed of the 42 selected banks and comparing the outputs from the single monolayer network to the multilayer network, it is possible to observe discrepancies between the centrality (degree and PageRank) for each bank. The results identified in the multilayer network analysis seem to bear higher consistency with the real scenario in the financial sector, since the mapping of Shareholder Banks shows that the fact that the position as shareholders influences the measures of its importance in the network. Moreover, since we focus not only on the quantitative measures of relations, but also on the qualitative part of the agents' characteristics (*'banks only'*, *'shareholder banks'* or both), we obtained a reliable measurement of the importance of each agent in the network by adding more information on the role of each bank in the network. This allows a more solid and less biased analysis of the financial market and the role of agents, based on the discrepancies found in degree and PageRank values identified in different approaches.

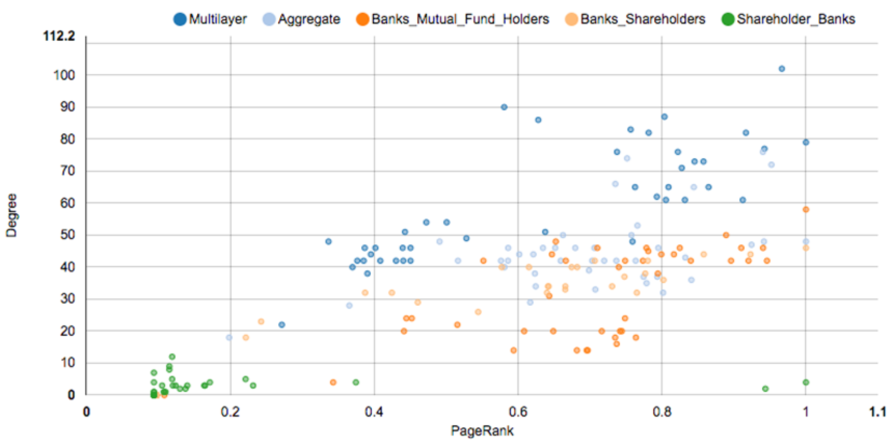

Fig. 1 Degree and Page Rank of multilayer and aggregate networks

Finally, after analyzing the network, it is possible to observe that JP Morgan is the most important bank in the network, followed by Deutsche Bank, Wells Fargo and Bank of America, since these banks have shareholding position in other banks or have shareholder banks. These characteristics allow them to have the highest PageRank of the network.

III. Discourse

Network theory is increasingly gaining importance in studies of diverse scientific fields, allowing analytical progresses that were previously impossible. The first graph appeared almost three centuries ago, as proposal to solve the problem of Königsberg [23], and the use of graphs and the theory of networks have spread along time, driven by the emergence of various softwares aimed at analyzing complex systems and the popularization of social networks. However, the network theory encompasses several mechanisms and concepts which allow a robust introductory analysis of the complex systems. There is still progress to be made in its representations to increase reliability of the network analysis, especially considering that recent studies on complex systems bring new techniques, premises and information. In this context, the emergence of mechanisms and concepts linked to multilayer networks has been shown to incorporate tools for the investigation of a wider and more diverse range of system and its agents.

Regarding studies and analyses of the financial system, it is possible to observe several advances related to the understanding of the market, considering diverse scenarios for assessment of the economic networks and its agents. However, it is important to point out that many studies like [18], [19] still adopt unidimensional analyses that ignore the complexity, resulting in inadequate conclusions of the current situation. Additionally, there are parameters that are still unexplored regarding the relationship between economic agents and their multiple roles in the market. Consequently, this work seeks to bring additional information to financial markets analysis, in order to try to reduce gaps in this field of knowledge, proposing the adoption of agents' characteristics (institutional shareholders) as additional parameters of relationships among financial institutions to allow multilayer network analysis.

IV. Methodology

Firstly, it should be pointed out that the selection of banks was based on their prominence on news published in newspapers and magazines during the period nearby the financial crisis of 2008, combined with information on their importance at that time and today, both in global banking market and in local economies of their countries of origin.

In order to structure the network, we chose to use the main shareholders institutions in each bank, in order to define the interactions among institutions, due to the role of this variable in influencing financial markets' agents. In addition, we wanted to avoid the usual approach in which the edges of the network are based on interbank loans [24]-[29].

Although the initial idea was to collect data in the period nearby the financial crisis from 2007 to 2009, most banks do not provide the information on their main institutional shareholders in the period select. Therefore, it was decided to use data referring to June 2017.

After data collection, banks and shareholders were listed to check the commonalities of shareholders among them, adopting weight 1 for each. However, the initial network representation with nodes representing the banks and amount of common shareholders representing the edges resulted in a complex network design with certain banks being also shareholders (Table I). Therefore, we built initially a network without the *'shareholder banks'* feature where banks assumed only the position of banks and the connections were indirect and had the weight according to the amount of mutual funds holder (Fig. 2) and shareholders (Fig. 3) between the banks. Gephi version 0.9.2 was the software used to create the networks in Figs. 2-4.

Fig. 2 Banks Network (edges are mutual funds holder in common)

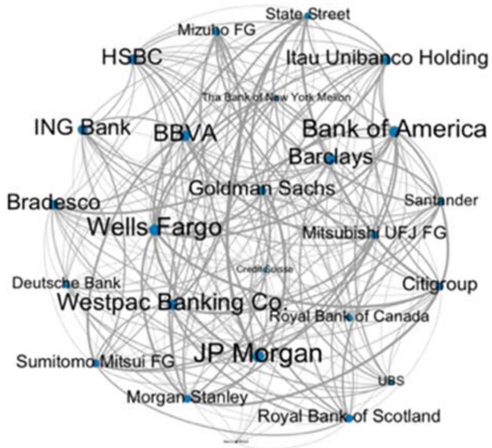

Fig. 3 Banks Network (edges are shareholder in common)

A second network was elaborated to include the *'shareholder banks'* and the banks in which they held shares, including directed connections with weight 1. However, the analysis of separate networks seemed inconsistent, due to the disconnection between both situations neglecting the fact that these occur simultaneously in aggregate form. Therefore, we chose to adopt a multilayer network to avoid the discarding relationships and characteristics of agents in the network that would provide important information in the analysis of the financial network, depicting in each layer a type of relation and interconnecting them through the nodes present in both. The software chosen at this stage was MuxViz (version 2.0). In addition, we analyzed the importance of the agents in the network by measuring the degree (number of connections between a node and others), considering that the most important node of the network is the one with the highest degree [30] – and the PageRank – search algorithm adopted by Google. Unlike the degree, PageRank differentiates the nodes, according to the nodes interconnected to each one. For the algorithm, the most important node is the one that interconnects with the greater number of "better" nodes (with higher quality/importance) [31]. However, considering works like [32], which shows that the Multiplex PageRank reflects the influence of the node importance in one layer affecting its importance in another layer, we decided to use only PageRank for measurement of the importance of nodes in the network, because it is a recursive measure where the measure of one node will depend on the measures of nodes connected to it, unlike the degree [33].

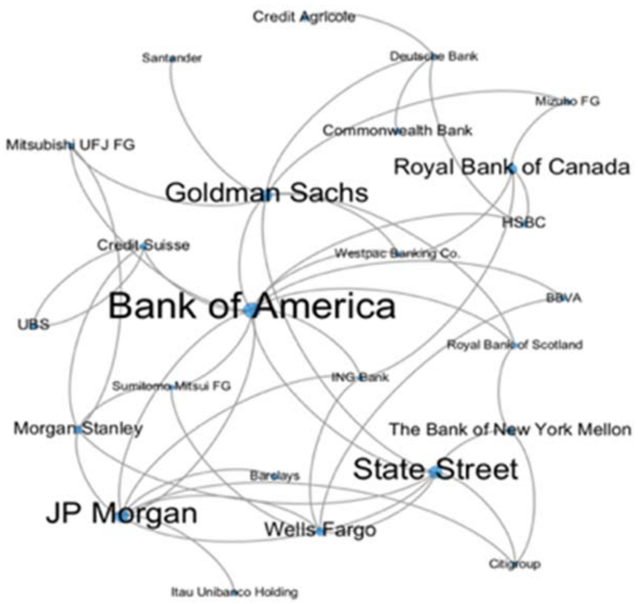

Fig. 3 Shareholder Banks Network

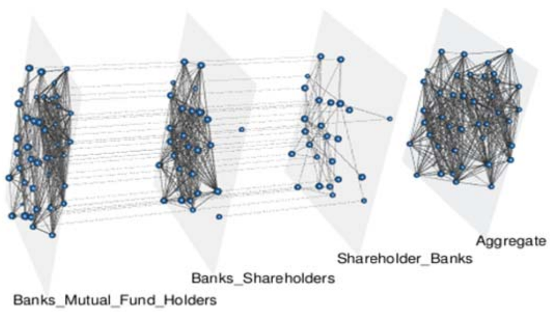

Fig. 4 Multilayer Network

The results obtained in both approaches were compared in order to demonstrate differences between networks' properties and characteristics, enabling to conclude that the multilayer approach presented more robust results in depicting the network, its agents' relationships and the roles in the financial market.

The multilayer network shows particularly the positive influence of institutional shareholder position in allowing improved intermediation capacity, with JP Morgan and Deutsche Bank being the most important banks in the network, not just because they are amongst the most interconnected nodes and have shareholding position in several other banks – higher degree – but mainly because they have relationships with other major banks – higher PageRank.

TABLE I
MEASURES OF CENTRALITY OF BANKS

Node	Label	Degree	DegreeOut	PageRank
7	JP Morgan	79	42	1.0
13	Deutsche Bank	102	49	0.9665
11	Wells Fargo	77	39	0.9423
4	Bank_of_America	82	45	0.9165
5	Citigroup	61	29	0.9122
9	The_Royal_Bank_of_Scotland	65	31	0.8646
42	Westpac_Banking_Corporation	73	35	0.8576
10	Barclays	73	36	0.8451
8	Morgan_Stanley	61	30	0.8317
3	Goldman_Sachs	71	38	0.8273
24	BBVA	76	37	0.8220
16	Mitsubishi_UFJ_FG	65	32	0.8089
27	State_Street	61	34	0.8053
34	Itau_Unibanco	87	43	0.8033
18	Mizuho_FG	62	30	0.7927
1	HSBC	82	40	0.7814
12	Santander	65	32	0.7625
21	Sumitomo_Mitsui_FG	48	22	0.7589
2	UBS	83	42	0.7564
20	ING_Bank	76	36	0.7373
26	The_Bank_of_New_York_ Mellon_Co	51	26	0.6376
40	Bradesco_SA	86	43	0.6279
32	Royal_Bank_of_Canada	90	47	0.5805
14	Credit_Agricole_SA	49	25	0.5280
6	Credit_Suisse	54	26	0.5006
15	BNP_Paribas_SA	54	27	0.4723
39	Intesa_Sanpaolo	46	23	0.4504
35	Industrial_and_Commercial_ Bank_of_China	42	21	0.4503
33	Commonwealth_Bank	51	26	0.4426
17	Bank_of_China	42	21	0.4403
36	Lloyds_Banking_Group	46	23	0.4394
30	Bank_of_Communications_Co	42	21	0.4302
31	China_Merchants_Bank	42	21	0.4084
29	Agricultural_Bank_of_China	46	23	0.4015
19	Societe_Generale	44	22	0.3952
28	China_Construtions_Bank	38	19	0.3904
25	Standard_Chartered	46	23	0.3867
38	Commerzbank_AG	42	21	0.3852
22	Unicredit_Group	42	21	0.3764
37	Citic_Limited	40	20	0.3697
23	Nordea_Bank	48	24	0.3364
41	Banco_do_Brasil_SA	22	11	0.2715

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