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Methodological Article

Board of Directors' Interlocks: A Social Network Analysis Tutorial

Conselhos de Administração Interligados: Um Tutorial de Análise de Redes Sociais

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ABSTRACT

Objective: the literature on board interlocks has increased in recent years, focusing on understanding board composition and its relationships with other companies' boards. Such studies usually require multiple procedures of data extraction, handling, and analysis to create and analyze social networks. However, these procedures are not standardized, and there is a lack of methodological instructions available to make this process easier for researchers. This tutorial intends to describe the logical steps taken to collect data, treat them, and map and measure the network properties to provide researchers with the sources to replicate it in their own research. We contribute to the literature in the management field by proposing an empirical methodological approach to conduct board interlocks' research. **Proposal:** our tutorial describes and provides examples of data collection, directors' data treatment, and the use of these data to map and measure network structural properties using an open-source tool — R statistical software. **Conclusions:** our main contribution is a tutorial detailing the steps required to map and analyze board interlocks, making this process easier, standardized, and more accessible for all researchers who wish to develop social network analysis studies.

Keywords: board interlocks; social network analysis; tutorial.

RESUMO

Objetivo: pesquisas sobre *board interlocks* vêm crescendo nos últimos anos, com foco no entendimento da composição dos conselhos assim como suas relações com conselhos de outras companhias. Esses estudos normalmente requerem múltiplos procedimentos de extração, tratamento e análise de dados para a criação e análise das redes sociais. Entretanto, esses procedimentos não são padronizados, havendo uma falta de estudos metodológicos com instruções para tornar este processo mais simples. Assim, este tutorial pretende descrever a sequência lógica de passos a serem percorridos para realização da coleta de dados, tratamento, mapeamento e análise das redes sociais, para prover aos pesquisadores os insumos necessários para replicação desses procedimentos em suas pesquisas. Nesse sentido, este tutorial contribui com a literatura no campo de pesquisa da administração por propor uma metodologia para condução de pesquisas em *board interlocks*. **Proposta:** o tutorial descreve e exemplifica a extração e tratamento dos dados das empresas e seus conselheiros, o uso destes dados no mapeamento das redes de *board interlock* e a medição de suas propriedades estruturais, utilizando uma ferramenta *open source*, o software estatístico R. **Conclusões:** nossa principal contribuição é fornecer um tutorial que orienta o processo de mapeamento e análise dos *board interlocks*, tornando-o mais acessível aos pesquisadores que desejam adotar esta abordagem de pesquisa.

Palavras-chave: *board interlocks*; análise de redes sociais; tutorial.

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INTRODUCTION

Within the increasing of corporate governance studies, board interlocks have become one of the most prominent research topics (Lamb & Roundy, 2016). The available literature defines a board as being interlocked when a director sitting on the board of directors of Company 'A' also sits on Company 'B' (Smith & Sarabi, 2021a). Interlocks can be explored from the companies' perspective or from the directors' perspective. When analyzed from companies' perspectives, the literature calls it 'board interlocks,' and focuses on evaluating the relationship formed between companies that share at least one director. Conversely, the literature names 'interlocking directorates' when we are looking for interlocks from directors' perspective, to understand the relationships and the links formed between directors (Fich & White, 2005). To explore interlocks, in this paper we use the first perspective, shedding light to the companies and their relationships through board interlocks.

Interlocked boards have become a focus of increasing attention in several countries around the world, including Singapore (Phan, Lee, & Lau, 2003), France (Yeo, Pochet, & Alcouffe, 2003), United States (Fich & White, 2005; Wong, Gygax, & Wang, 2015), Italy (Drago, Millo, Ricciuti, & Santella, 2015), India (Helmers, Patnam, & Rau, 2017), and Saudi Arabia (Hamdan, 2018). Lamb and Roundy (2016) conducted a systematic review of board interlocks studies and presented many applications relating board interlocks to a range of corporate aspects, such as its impacts on company performance (Davis & Cobb, 2010; Hillman, Withers, & Collins, 2009; Pfeffer, 1983), or how companies manage environmental uncertainty (Useem, 1986). They also present studies regarding board interlocks serving as a sign of a firm's quality (Certo, 2003; Higgins & Gulati, 2003; Kang, 2008), or even how interlocks can facilitate access to unique and distinct information from interlocked companies (Haunschild & Beckman, 1998).

Since 2009, the CVM Ordinance 480 (Comissão de Valores Mobiliários, 2009) has established that Brazilian public companies must disclose their corporate governance (board composition, committees, executive compensation, governance practices, and so on) and financial data (financial statements) to the regulator (CVM — *Comissão de Valores Mobiliários*) once a year through the Reference Form (*Formulário de Referência*). An extensive part of the information required is filled by the companies manually and there is no validation of the data provided, while some companies have initially refused to comply with executive compensation disclosure by using a court injunction (Costa, Galdi, Motoki, & Sanchez, 2016). These features may contribute to a lack of pattern as well as missing information in the data used by researchers, requiring further procedures and reliability analysis.

Besides that, the number of studies using data from Reference Form has increased in recent years. Sprenger, Kronbauer, and Costa (2017) conducted data collection from Reference Form in 2017, focusing in understand CEO features and its effects on earnings management. The authors have collected CEO features such as name, age, experience, education, duality, and type of election manually. The data collection has become easier since the issuing of R packages to do so, such as GetFREData package (Perlin, Kirch, & Vancin, 2018). Locatelli, Ramos, and Costa (2021) used this package to collect Brazilian companies' data from Reference Form from 2012 to 2018 to evaluate the effects of social ties on CEO turnover. Likewise, Mastella, Vancin, Perlin, and Kirch (2021) also collected data from Reference Form to investigate the effects of board gender diversity on performance and risk taking in Brazilian companies. Beuren, Pamplona, and Leite (2020) also used the same dataset to investigate the relationship between executive compensation and the performance of family and non-family Brazilian companies, while Rodrigues and Galdi (2017) used the data from Reference Form to evaluate investor relations and information asymmetry in Brazilian companies. All these studies relied on further analysis and manual procedures of data handling and processing to identify incorrect information and correct it before creating variables and econometric models. There is no requirement of board interlocks' disclosure on the Reference Form. In this sense, it is not possible to find explicitly the interlocks formed between companies that share at least one director. That is one of the reasons why when conducting board interlocks studies, the researcher must collect data from the Reference Form, analyze its reliability and then run the procedures to identify the connections between companies through board interlocks. Smith and Sarabi (2021b) pointed out topics not yet explored in board interlocks studies, such as: (a) how board diversity develops within the interlocking network and affects performances; (b) interlocks and corporate governance structures in emerging economies; and (c) new theoretical approaches, aiming to compare different institutional settings and countries. The first two topics are empirical avenues of research still unexplored and that can be studied in the Brazilian context using the data available and the methods of social network analysis (SNA) presented in this article. Other unexplored possibilities of use of SNA to study Brazilian corporate governance data include analyzing Fiscal Council members' networks, and networks of board members appointed by state-owned enterprises and/or institutional investors.

A social network is a collection of individuals or companies interconnected by many different sorts of links (Lazzarini, 2008). SNA can be used to analyze the consequences or causes of board interlocks existence. One of the challenges faced by researchers is to obtain access to a detailed dataset related to board members and companies. Usually, these datasets are not easily manageable. In some countries, such as Brazil, the data for public companies is non-structured, so researchers must follow many steps in the performance of their research, which require a lot of hand-collected data. Another drawback in this field of research is that the procedures to create and analyze networks' measures are usually not well detailed in the previous studies. This can be a result of word limitations or standards from different fields of study and journals. Therefore, it is hard to find some standard or guidance when conducting social network analysis research. In this tutorial, we aim to explain with details, step by step, the procedures involved in the conducting of data collection, data treatment, and how to map and measure the network properties of board interlocks. This study contributes to the literature in several ways: (a) by establishing a methodological way to conduct procedures and handle social network analysis; (b) by providing researchers with practical instructions to properly conduct these procedures, spending less time in manual tasks, increasing data reliability; and (c) providing a standard to conduct such tasks. This study can also encourage more masters and PhD students to explore the SNA and board interlocks fields of study, not yet widely explored in Brazil.

Furthermore, this tutorial can be of interest of researchers analyzing the "G" of the recent ESG topics, including the causes and consequences of the relationships between different actors (e.g., companies and directors). Within the corporate governance context, the method proposed in this tutorial makes it possible to analyze the composition of the networks, encompassing relevant issues such as diversity and connectivity of boards. For example, we may investigate if while pushing the gender diversity agenda companies become more connected as the presence of women increases, or alternatively may be resulting in the 'super-connected director' phenomena (Crabtree, 2011). In addition, our tutorial may allow researchers to evaluate how connections between companies from different sectors affect different aspects of corporate governance, including ESG requirements and policies (Harjoto & Wang, 2020).

Additionally, we briefly discuss SNA concepts and the ideas presented in the most high-impact studies available in this field, shedding light to possibilities of studies using SNA. Even though in this study we explore board interlocks, SNA can be used as a framework to understand relationships and behaviors across many other research subjects. For instance, in management it can be used to evaluate the relationship between countries through trading patterns (Smith & Sarabi, 2021a), and in medical studies, by evaluating the social interactions across animal species (Rocha, Ryckebusch, Schoors, & Smith, 2021). To illustrate the process focused on this paper, we used a database of Brazilian listed companies in 2019 and 2020 to set out the networks and measure their properties, using R Studio to apply the steps described. The sample resulted in 592 companies listed in 2019 and 629 companies in 2020.

This article is organized as follows: we first present the literature concerning board interlock and SNA; the following section describes how to measure interlocks in our dataset, following the steps of data collection and treatment, forming a relational matrix, and then visualizing and measuring board interlocks using R; finally, we explore some of the advantages and limitations of the method and present our concluding remarks.

BOARD INTERLOCKS LITERATURE

Board interlock is the relationship between two company boards when they share at least one director. In other words, board interlock occurs when a director of company 'A' also belongs to the board of directors of company 'B' (Fich & White, 2005). Besides this, a board interlocking network is a group of company boards and all the interlocks among them (Wong et al., 2015). Board interlock can include studies in different fields, such as finance, governance, and sociology.

Interlocks can be seen as a communication tool between different companies. Lamb and Roundy (2016) showed that interlock research could adopt two perspectives: the company's perspective and the director's perspective. Interlocks can occur from a company standpoint to create links between companies, reach financial objectives, reduce environmental uncertainty, or improve the board monitoring ability. In addition, companies can be interlocked as a signal to current and potential investors. For example, when a company appoints a director from a corporation with a high reputation, this can signal its quality. From the director's perspective, they found that the directors want to be interlocked to advance their careers and extend their connections by making social links.

Board interlock studies have been increasing over time. Many try to find evidence of board interlocking consequences, such as the effects of board interlocking on strategic decision-making, such as the design of CEO compensation package (Fich & White, 2003; Larcker, Richardson, Seary, & Tuna, 2005), earnings management (Tham, Sultana, Singh, & Taplin, 2019), company performance (Vesco & Beuren, 2016), and the strength of corporate governance (Silva, Silva, Vasconcelos, & Crisóstomo, 2019). Bebchuk and Fried (2004) also showed that the monitoring function could fail when a director serves several boards. They would be more likely to agree with CEOs' opportunistic behavior or other situations in which the shareholder's profit maximization could be injured. On the other hand, Mazzola, Perrone, and Kamuriwo (2016) argued that interlocked companies are more likely to achieve new product development outcomes due to providing experience sharing and information to mitigate drawbacks. By this view, board interlock could accelerate the development process of new products.

Each country has its laws designed to regulate board interlocks. In Brazil, Federal Law 6,404/76 has established that a director who sits on a company's board may not be elected to sit on a concurrent company board (Lei n. 6.404, 1976). However, such an arrangement is not prohibited. The ruling is often different in other countries such as the U.S., where the Clayton Act (1914) restricts directors from sitting on two boards of competitor companies. Besides this, public companies in Brazil do not have to directly disclose the interlocks between their directors. Hence, in such a case, to identify interlocks between companies, it is necessary to obtain the board composition from the Reference Form, which consists of a set of information that public companies need to deliver to CVM annually. There is a range of information available in this document, such as board composition, board and CEO features, as well as several financial and economic data. As we will explain in the following sections, we then need to perform procedures on the database extracted to identify interlocks. This kind of database makes it possible to map the network formed between public companies and directors and analyze the existent patterns of relationships. An effective way of doing this is using social network analysis tools.

SOCIAL NETWORK ANALYSIS (SNA)

The network analysis in the structural approach first verifies the existence of connections between two or more nodes and is interested in how these connections affect their behavior (Kilduff & Tsai, 2003). The nodes represent the actors, and lines represent the relationship between them. Nodes are the entities that make up a system, and these can be individual agents, like each person, or groups of individuals like teams; they can also be events, companies, or countries (Everett & Borgatti, 2013). The lines, meanwhile, represent social relationships that connect the nodes of that system. Thus, the system is an intuitive representation of the structure of existing relationships for a given network, which, in SNA language, is a network graph or sociogram (Scott, 1992).

Cohesion and density

The most relevant structural properties in the SNA for a network are characterized as cohesion, involving such elements as density, centralization, and centrality (Borgatti, Everett, & Johnson, 2018; Scott, 1992). Density is a property at the network level indicating how compact or cohesive the network is. It is obtained by measuring the general level of connections between all the participant nodes and is used for comparing different networks (Kilduff & Tsai, 2003). In quantitative terms, it corresponds to the number of connections and is expressed as a proportion over the number of possible links (Borgatti et al., 2018). It can vary from zero to one, reaching the value '1' when there are connections between all the participating nodes (Wasserman & Faust, 1994). For example, Croci and Grassi (2014) measured the network density of the companies listed on the Italian Stock Exchange, obtaining the value of 0.0268 for the main component. In that paper, this value is associated to a tendency of companies to be strategically connected.

However, density does not state how the links are distributed across the network. Other cohesion measures that help in this respect are the number of components, their size, and the degree of connectedness or fragmentation. The larger the main component (component with the higher number of nodes in the network), the greater the number of nodes that are part of this component and the greater the global cohesion of the network (Borgatti et al., 2018). Connectedness is the proportion between pairs of nodes that can reach each other by a certain path, while fragmentation measures precisely the opposite, that is, the ratio between pairs of unreachable nodes (Borgatti et al., 2018). The connectedness is calculated using Equation 1, and the fragmentation is one minus connectedness (Borgatti et al., 2018).

$$C_i = \frac{\sum_{i \neq j} r_{ij}}{n(n-1)} \quad (1)$$

in which i and j are nodes, r equals 1 if the nodes i and j are in the same component, and zero otherwise. Dahlin and Patel (2022), for example, studied board interlocks in different counties of Sweden and found a high level of fragmentation in all of them. The networks had approximately 6,000 components and 11,000 companies, with many isolated. In the paper's context, these structural characteristics were associated with difficulties in the spread of information.

Centrality measures

The centrality property allows identification of the importance or 'degree of popularity' of a particular node (Scott, 1992), therefore, a property at the node's level. From the perspective of the position of the nodes in the networks, we can observe three essential types of centralities: degree centrality, closeness centrality, and betweenness centrality. These metrics reflect the importance of individual nodes in a network under different aspects (Wasserman & Faust, 1994).

Degree centrality is that central node with the most links with other nodes in the network (Lazzarini, 2008). According to Zhu, Watts, and Chen (2010), degree centrality measures the number of links with other nodes in the network. In business power studies, for example, the literature points out that those nodes with a high degree of centrality generally exercise dominance over more peripheral nodes (Kilduff & Tsai, 2003). By the adjacency matrix X of a network, degree centrality is a simple sum of rows or columns of the adjacency matrix. If d_i is the degree centrality of node i and x_{ij} is the (i, j) record of the adjacency matrix, it must be calculated as in Equation 2 (Borgatti, Mehra, Brass, & Labianca, 2009).

$$d_i = \sum_{j=1}^{N} x_{ij} \tag{2}$$

In the example of the Italian companies (Croci & Grassi, 2014), the average degree centrality measured for the main component was 5.4879, ranging from 1 to 32, being Pirelli & C. the company with the highest degree centrality and so the most influent and powerful one.

Closeness centrality measures how close a node is to all the other nodes in the set of nodes (Wasserman & Faust, 1994). We can interpret closeness centrality as the minimum time the flow of information needs to arrive at another node in the network (Borgatti et al., 2009). Freeman, Roeder, and Mulholland (1979) posit that closeness centrality is the distance from a node to all the others, where the smaller values identify highly central nodes. Researchers often use a normalized version, dividing each node centrality into n-1, reversing the values so that large numbers correspond to greater centrality, ranging from zero to one. Thus, the normalized closeness centrality of node i will be represented by Equation 3.

$$c_i = \frac{(N-1)}{\sum_{j=1}^{N} d(i, j)} \tag{3}$$

where N is the number of nodes and $d(i,j)$ is the function of the distance between i and j. In a study evaluating the performance of Chinese foundations, for example, a high level of closeness centrality of the board interlocking of these institutions appeared as a factor that affects positively the outcomes of income and public welfare expenditure (Wu, Zhang, & Chen, 2021).

Finally, betweenness centrality highlights nodes that connect different nodes or groups of individuals in the network (Wasserman & Faust, 1994). It can explain the power of influence a node has in a network because it joins other nodes or groups isolated amongst the other nodes in a network (Zhu, Watts, & Chen, 2010). We calculate the betweenness centrality of node i using Equation 4.

$$b_i = \sum_{j<k}^{N} \frac{g_{jik}}{g_{jk}} \tag{4}$$

where g_{jik} is the number of ways connecting j and k through i, and g_{jk} is the total number of ways connecting j and k. Using again the example of the Italian Stock Exchange companies (Croci & Grassi, 2014), the minimum and maximum values measured for betweenness centrality were respectively 0 and 0.1506. Pirelli & C. was the company with the higher score, thus being in a position to receive and distribute a high volume of information.

The study of interlocked boards using SNA involves a particular network analysis mode, called two-mode data or affiliation data (Borgatti et al., 2018). There are two types of actors: the directors (the first mode), and the events, which are the boards of affiliated companies (second mode). The literature usually defines the companies/boards as the nodes of the network and the links between the companies as the interlocks (Scott, 1992).

INVESTIGATING BOARD INTERLOCKS: A TUTORIAL ON BRAZILIAN LISTED COMPANIES

We take certain essential steps to measure the interlocks between directors and companies in the Brazilian market: first, we perform the data collection procedures from a specific package on R software, with some searching parameters. Second, the data are treated using automatic methods on R. Third, we build the adjacency matrix to identify companies' relationships through the sharing of at least one director. Finally, we map the network and measure it using R. A summary of the steps is provided in Figure 1.

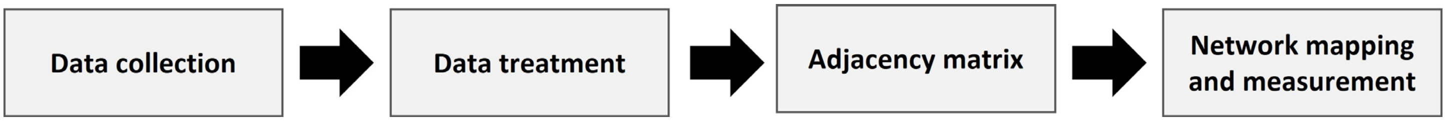

Figure 1. Step-by-step process taken to measure interlocks in Brazilian companies.
This paper describes these overall steps for the conducting of board interlock research using the databases of Brazilian companies.

As an empirical example of our method, we used a publicly listed dataset of Brazilian companies covering 2019 and 2020. Each step required to conduct the procedures is described over the course of this paper, and these procedures can be replicated using the code available.

Collecting and treating Brazilian companies' data (#Step1 to #Step5)

The first step involves the collection of corporate data from the Reference Form (FRE). These data are available on the CVM website. Although these are publicly available data, it would have been necessary to extract them individually for each company if we had to use the website. To collect the corporate data on a range of companies, we used the GetFREData package (Perlin et al., 2018) from R statistic software. The additional packages used in this tutorial are described in our code, and these packages can be replicated with script "1" (#packages and libraries). #Step1 of our code allows the researcher to collect data on Brazilian public companies available on the FRE, by simply selecting the period requiring analysis. However, connection problems or high latency can interrupt the download. In these cases, the program will present a warning such as "Try rerunning the code as the corrupted zip file was deleted and will be downloaded again." The user then needs to run #Step1 again, and this time the program will check the companies already downloaded and jump to a download of the remaining companies. The files relating to companies that have already been downloaded will not be downloaded again because the files have been saved in the cache.

Moreover, data collection could take a while because it downloads and reads each company's FRE files. We therefore provided a ready dataset like the one created by running #Step1 in .rds format (R native database). This dataset is available to import .rds file in #Step2, choosing the *I_fre.rds* file that is available in the attachments to this paper. This was done to optimize the length of time taken for data collection. We collected this database while this paper was being created, meaning some data could be outdated. To reach the updated database, we suggest running #Step1.

Once the data collection process has finished (on #Step1 or #Step2), we have a list containing all of the companies' available corporate FRE data. As we focus on the board of directors' composition and its connections, we will select only the data we need in #Step3. To get only the members of the board of directors, we filter the type of director, setting the *code.type.job* variable of the *df_board_composition*.

The result of #Step3 is a table with the company name, CNPJ (*Cadastro Nacional de Pessoa Jurídica*), the corporate registration number with the Brazilian tax authority (*Receita Federal do Brasil*), company name, reference date (information date), CVM code, director's name, and CPF (individual taxpayer registration) number, which is a document provided by the Brazilian tax authority to identify Brazilian citizens and foreign citizens resident as taxpayers in Brazil. As the companies fill out the form on FRE manually, there is a strong likelihood of mistakes existing in the information. Usually, we can find some errors in FRE, such as CPFs with less than 11 digits or even CPF information missing entirely. The lack of standardized information could interfere with our analysis. Therefore, we provide data treatment procedures to mitigate this risk and correct the original database's common mistakes.

First, we standardize the names and CPFs of the directors using #Step4. After this, we take those cases where the CPF information is missing or incorrect and search for each director's correct CPF in other entered cases. Finally, if we could not find the CPF, we create a code for this director instead of the CPF to keep a unique code for each director in our database. To do this, we run #Step5. These procedures are essential to be able to correct errors in the dataset and to guarantee its reliability.

Creating the adjacency matrix using R Studio (#Step6 and #Step7)

To illustrate some possibilities for the application of SNA to board interlocks, we used *IGraph package* (Csardi & Nepusz, 2006) to generate the graphs in R, which provides graph characteristics and manipulates a large and complex network (Meghanathan, 2017). We used the *SNA package* (Butts, 2008) to generate and analyze the network measures and *Keyplayer package* (An & Liu, 2016) to generate the fragmentation measure.

The relational matrix allows us to identify the relationship between two or more companies that share at least one director. Each matrix cell shows whether a node A is interconnected with a node B (Lazzarini, 2008). For instance, we create two relational matrices, one for each year of our sample, 2019 and 2020. First, we create a matrix with the company and directors, using companies and directors' previously created codes. This matrix identifies each director and enters the information '1' when the director sits on the respective company's board of directors. We then multiply this matrix by its transposed matrix to establish a 'companies x companies' square matrix. In this new matrix, we can identify the number of directors that companies share at that time. The diagonal matrix will be entered as zero because it means the relationship between the company and itself. This process is detailed in #Step6 for each year that we want to create the relational matrix.

We can also plot the network graphs for each year of our sample in the same step, using the commands described. The outcome is shown in Figure 2. This visual comparison did not show significant change in the general configuration of our sample's network. The pattern of relationship among the companies has remained relatively similar from one year to the next. Both sociograms represent relatively low density, high fragmented networks. Part of the companies are connected forming a great group, other parts constitute small subgroups of two (diads), three (triads), or more companies and the rest of the companies are isolated, not connected to any other company.

Now, we finally have the relational matrix and the networks ready. We can also export the matrix in CSV format by using #Step7, which can be used to map and generate the network measures in software different to R. The matrix created is shown in Figure 3. We will then present the steps for measuring and visualizing networks using R.

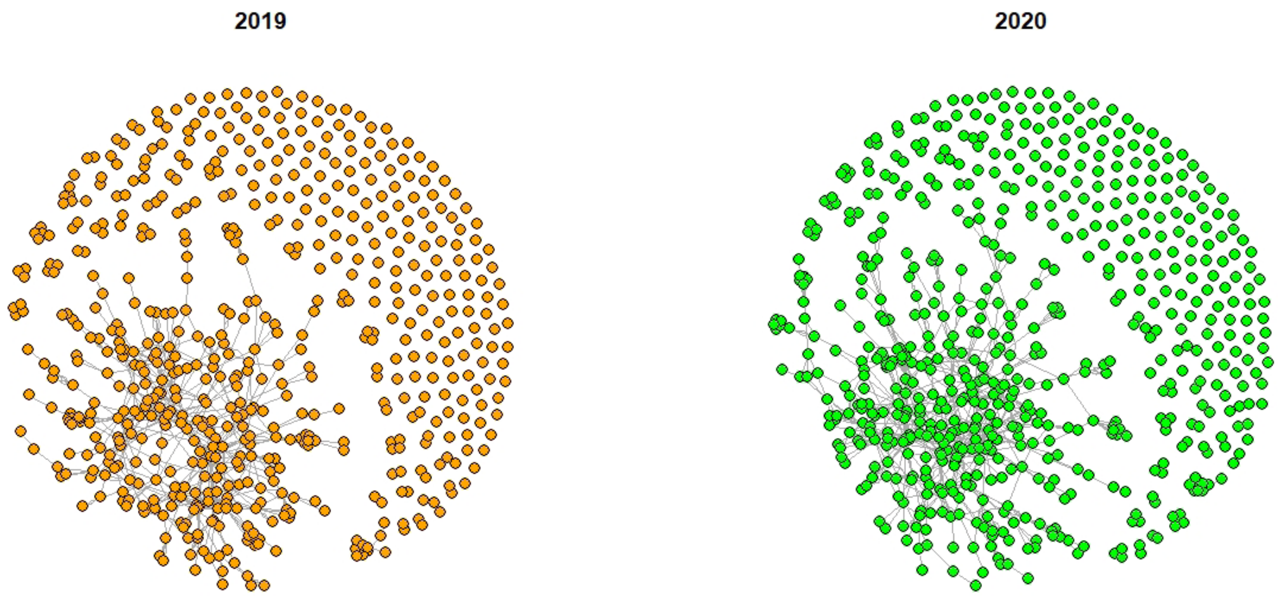

Figure 2. Network graphs.

Figure 2 shows the outcome of #Step6 of the code, representing the entire network between Brazilian companies each year. It can also be replicated with script "191."

	94	701	906	922	1023	1120	1155	1171	1210	1228	1309	1325	1384	1520	1562
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
701	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
906	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
922	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1023	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1120	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1210	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1228	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1309	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
1325	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
1384	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1520	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1562	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Figure 3. Example of adjacency matrix for 2019.

Figure 3 shows the outcome of #Step7 of the code, representing the adjacency matrix created with the companies from our sample. This also shows the relationship between companies by filling the cells with the number of directors they share in this year. Notice that companies 1309 and 1325 share two directors.

Visualizing and measuring board interlocks using R Studio (#Step8 to #Step10)

Our empirical example generates measures at the network's level: size, density, degree of centralization, betweenness centralization, closeness centralization, connectedness, and fragmentation. In #Step8 we create a data frame with these measures for each year, making comparisons and analyses. The results are shown in Table 1. In the same step, we create a data frame with only the centrality measures (degree, betweenness, and closeness) for each sample company. A sample of these results is shown in Table 2, showing where we selected specific companies to illustrate how the data is shown. These results can be exported for analysis and included in the econometric models as interest, independent, or moderating variables, according to the needs of each study.

These network measures could be used as variables in econometric models. To do this, we join the measures for all years of the sample. In Table 3, we show the descriptive statistics of the consolidated sample for each variable. This procedure is described in #Step9.

Table 1. Network measures (general).

Year	Size	Density	Degree	Betweenness	Closeness	Fragmentation	Connectedness	Components
2019	419	0.0158	0.0586	0.0987	0.2560	0.9036	0.471	45
2020	466	0.0135	0.0555	0.0762	0.2394	0.8950	0.549	46

Note. This table shows all measurements created with our code in #Step8. It can be replicated with script "217."

Table 2. 2019 network measurements (for each company).

Company	Degree	Betweenness	Closeness
701	5	0	0.1808
906	24	429.98	0.161
922	3	285	0.1432
1023	8	2799.32	0.2008
1120	1	0	0.1122
1210	4	285	0.1004
1228	1	0	0.1224
1309	4	1	0.0024
1325	2	0	0.0018
1384	11	0	0.1414

Note. This table shows the network centrality measurements created in #Step8: degree centrality, betweenness centrality, and closeness centrality. It can be replicated with script "217." Source: The authors.

Table 3. Descriptive statistics.

Variables	Means	Median	Min	Max	Q1	Q2	Q3	SD
Degree	6.52	4.00	1.00	32.00	2.00	4.00	9.00	6.04
Betweenness	523.58	0.14	0.00	9160.19	0.00	0.14	577.94	1093.64
Closeness	0.11	0.13	0.00	0.23	0.01	0.13	0.16	0.07
Fragmentation	0.89	0.89	0.89	0.90	0.89	0.89	0.90	0.00
Component	7.31	1.00	1.00	46.00	1.00	1.00	7.00	11.94

Note. This table shows the descriptive statistics from our sample (2019 and 2020), based on the variables created in the previous steps. It is possible to generate these statistics for each year of the sample. These data will be used as variables in the econometric models. Source: The authors.

Taking a closer look at 'degree' in Table 3, the average of interlocks established between companies is 6.52. Meanwhile, the median is four, which means that the interlocked companies usually share four directors. The minimum number of directors companies share is one (because we are considering only the interlocked companies) and the maximum is 32. Coincidently, this is the same maximum number as in Croci and Grassi (2014). After this, we can generate the graphs based on the measures in #Step9. The first is degree centrality, which shows the nodes that are more central in the network. Our empirical example shows the more prominent companies in the Brazilian market environment in a bigger size, considering the amount of board interlocking between them.

In this case, the more prominent companies are those that have the greatest number of connections with other companies, directly or indirectly (Figure 3). Like in Figure 2, the visualization of these sociograms permits to conclude that the general pattern of relationship of the network has remained from 2019 to 2020, with a significant number of central companies. However, some changes could be happening on companies that are more central. This identification is facilitated using the degree centrality measure (see Table 4).

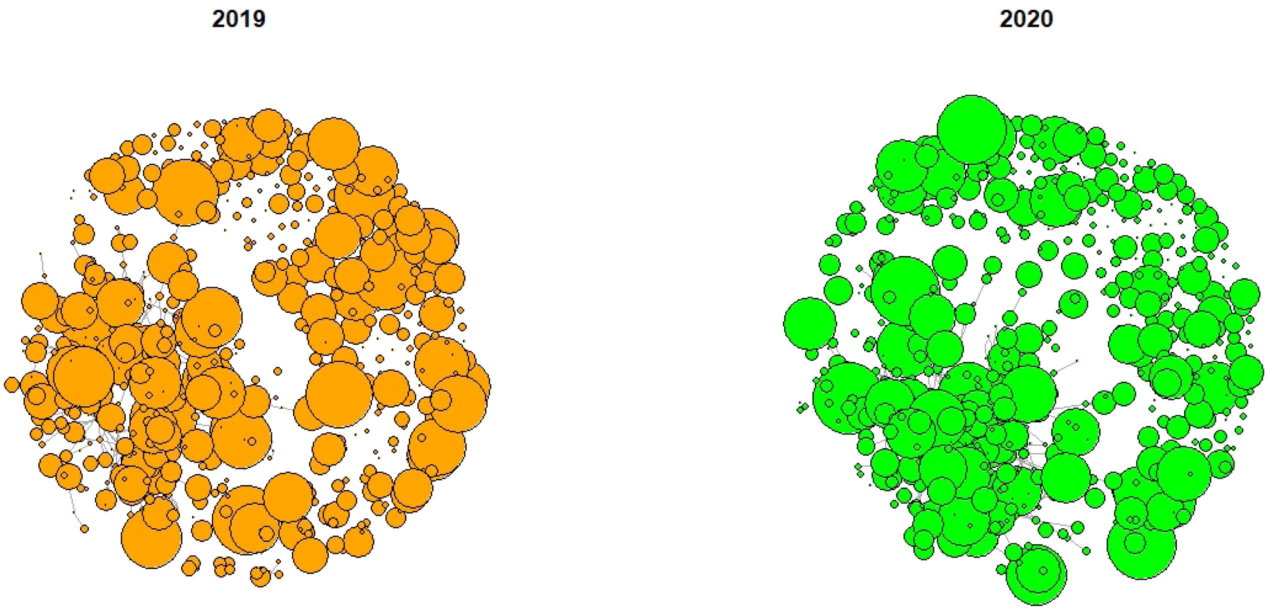

Figure 4. Degree centrality.
This figure presents the centrality degree of our network provided by #Step10. It can be replicated with script "324/degree network graph."

Following, running #Step10, we can also generate the histogram of degree centrality. It shows the distribution of degree centrality in the companies of our sample. We can see from our empirical example that in both years, most companies have a lower degree of centrality in the network by sharing from zero to five directors (the more peripheral ones). Few companies share more than 20 directors in our sample in both years. The histogram is illustrated in Figure 5.

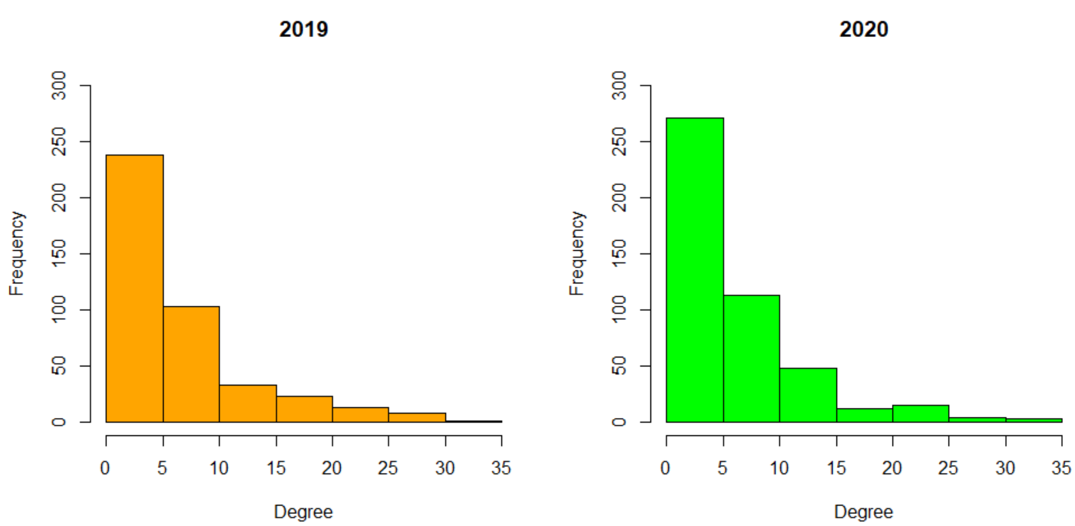

Figure 5. Degree centrality histogram.
This figure shows the distribution of degree centrality in our sample, as provided by #Step10. It can be replicated with script "342/degree histogram."

Again, the graphs for 2019 and 2020 are similar, with few differences in the distribution of the number of directors shared by the companies. Variations that are more significant probably could happen comparing longer periods.

Another possible analysis regarding the degree centrality involves a comparison of the companies with the highest degree of centrality to identify eventual changes. To exemplify this, we listed companies with a degree centrality higher than 24 (Table 4). Companies marked in bold represent changes in degree centrality to top companies. We can see that the top seven central companies remain the same, but important changes happened with the emergence of company 18139 and loss of prominence of companies 21822, 21857, and 00906. Company 18139 is now in position to share information and experiences with a large number of other companies, and then obtain benefits such as better strategic decisions (Fich & White, 2003; Larcker et al., 2005) and the acceleration of the development of new products (Mazzola, Perrone, & Kamuriwo, 2016).

Table 4. Companies with degree centrality above 24.

2019		2020	
Degree	Company	Degree	Company
31	21938	32	21938
30	03271	31	03271
30	18996	31	18996
27	02453	27	02453
27	15253	27	20303
27	20303	27	20320
27	20320	26	15253
26	**21822**	24	03190
26	**21857**	24	05576
24	**00906**	24	14605
24	03190	**24**	**18139**
24	05576		
24	14605		

Note. This table shows the differences in degree centrality in different years of our sample. We can see in bold that the companies 21822, 21857, and 00906 that appear with degree centrality above 24 in 2019 did not appear as having higher degree centrality in 2020. It can be replicated using #Step8 (Network measures tables) with script "262."
Source: The authors.

Our third graph (Figure 6) presents the betweenness centrality, showing in a bigger size the companies that act as a bridge in the network by connecting different companies. A simple comparison of the sociograms makes it possible to verify that there was an increase in the number of companies with high intermediation centrality. That is, there are more companies in a privileged position, being able to influence or restrict the interactions between other companies and obtain benefit from that (Zhu et al., 2010).

As in the case of degree centrality, it is interesting to compare the companies with the highest values of betweenness centrality to identify eventual changes. In Table 6, we listed the first 15 companies with the highest betweenness centrality each year. Companies marked in bold represent the changes observed. There were more changes in betweenness centrality than in degree centrality. It means that there are more new companies in this privileged position and that several other companies lost this privilege due to changes in the composition of the companies' boards. This privileged position can imply that companies with higher betweenness centrality could control the flow of information in the network. As long as this structure changes over time, information flow can also change.

Finally, we created the normalized closeness graph (Figure 7), showing the lower distances from one node to all the others. A high level of closeness indicates that a node is highly central. Our sample shows that many companies are central in the network since there are many big-sized nodes. It means, for example, that companies with high values of closeness centrality potentially receive information from a random company very quickly and with less distortion (Borgatti et al., 2018). Once more, the network configuration from one year to another is similar.

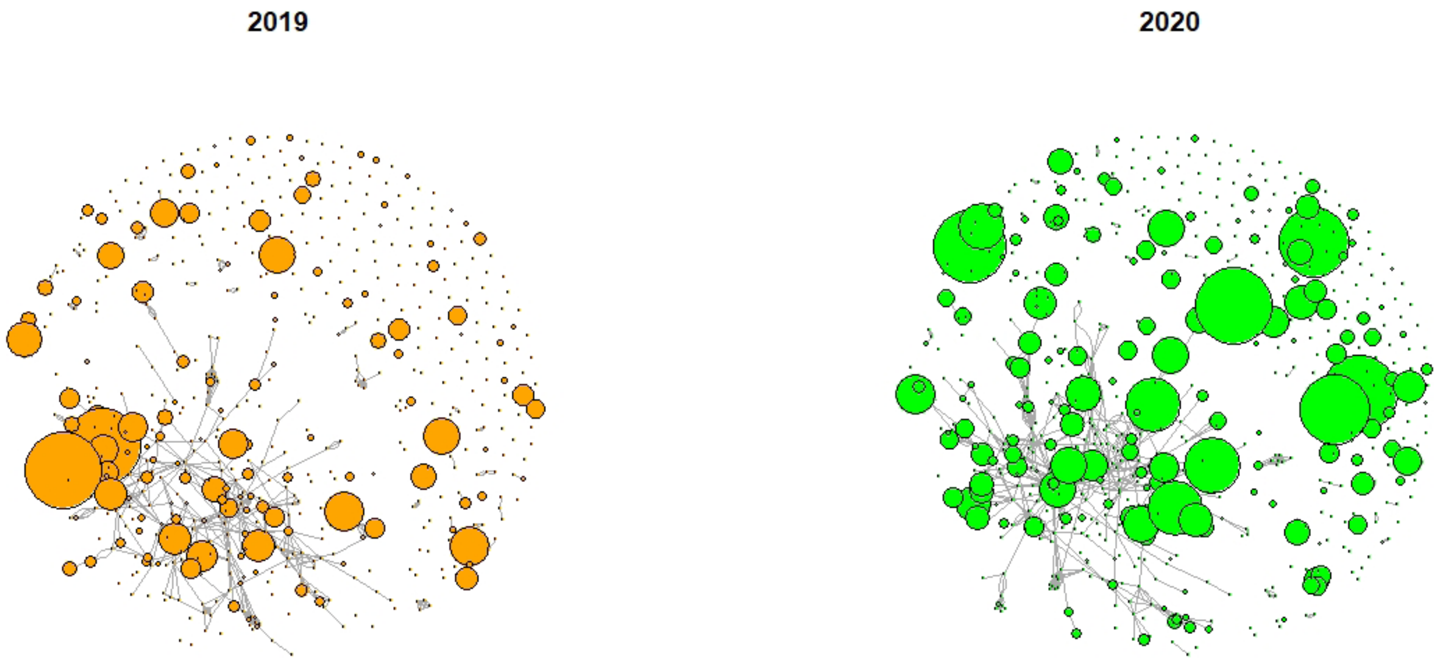

Figure 6. Betweenness centrality.

This figure shows those companies with higher betweenness centrality as more prominent nodes. These companies act as a bridge in the network, joining different companies by sharing their directors. It can be replicated using #Step10 with script "350/betweenness network graphs."

Table 5. Companies with the highest betweenness centrality.

2019		2020	
Betweenness	Company	Betweenness	Company
8994	**02437**	8801	**08133**
4626	16292	8120	20087
4414	**08133**	8027	09512
4164	**24694**	6441	**21016**
3720	**22055**	6413	16292
3622	**18465**	5341	**21237**
3607	**20028**	4456	**21091**
3600	04820	4294	**17973**
3525	20087	4236	**13986**
3416	**24295**	4172	19992
3251	19992	4051	04820
2985	**12653**	3935	**16616**
2824	**22349**	3851	**21199**
2799	**01023**	3778	**19836**
2560	09512	3617	**24902**

Note. This table shows the differences in betweenness centrality in the different years of our sample. We can see in bold that some companies, such as 02437, appear with betweenness centrality of 8994 in 2019 but do not appear amongst the higher betweenness centrality in 2020. This can be replicated using #Step8 (Network measures tables) with script "262."

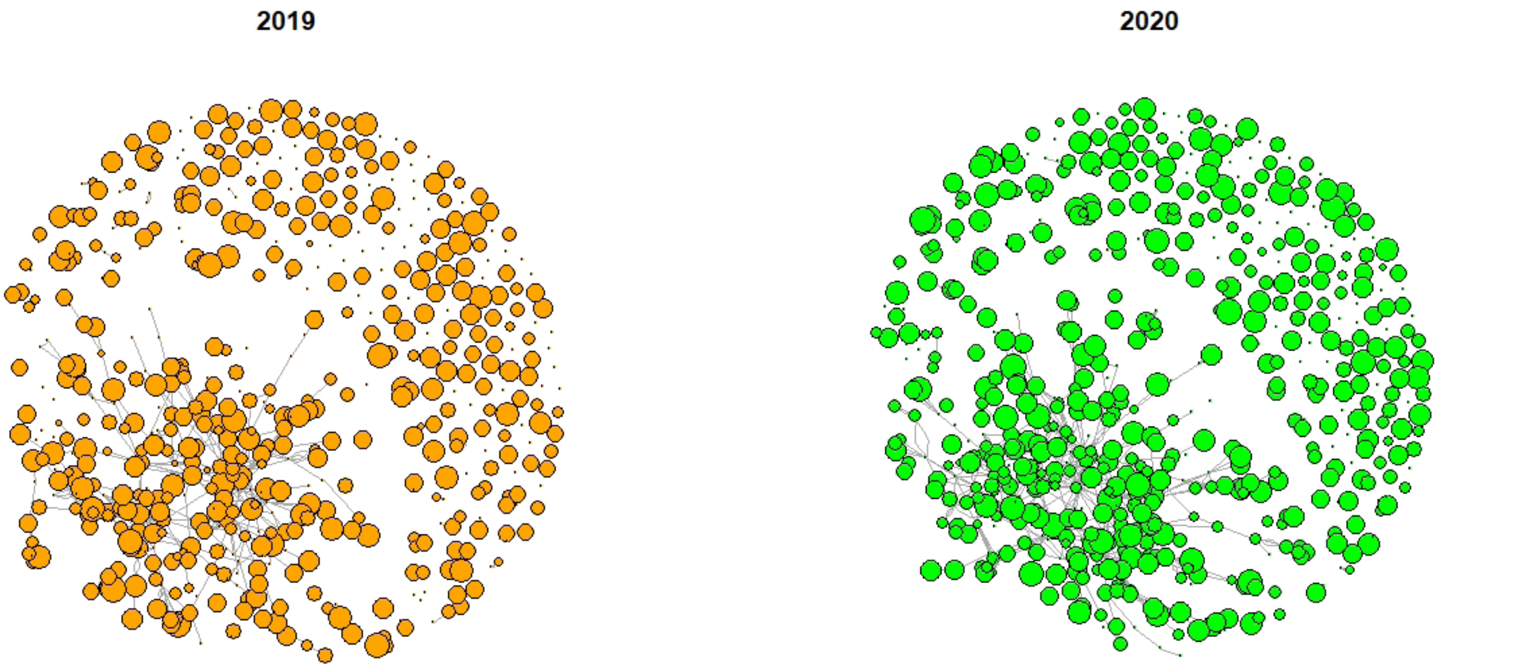

Figure 7. Closeness centrality (normalized).

This figure presents the companies with higher closeness centrality as more prominent nodes. These companies have many direct connections with other companies by sharing their directors. This can be replicated using #Step10 with script "368/closeness network graphs."

Only by seeing the graphs presented in Figures 2, 4, 6, and 7, is it possible to understand that the network in both years has a lower cohesion and a significant level of fragmentation, with a high number of components, some of which are with a small number of companies. Data presented in Table 1 complement this qualitative evaluation, informing each year's density, number of components, and the fragmentation and connectedness indexes. These measurements, along with the centralization, indicate few changes in network level analysis when comparing 2019 with 2020. On the other hand, measurements at the level of the nodes, especially the betweenness centrality, denote significant changes in the positions of the companies. Some companies that were privileged in 2019 in terms of their power of influence have lost those positions to other companies that have become more central in 2020.

All the steps taken throughout this tutorial, from data collection, treatment, and possibilities of use are summarized in Table 6. It is noteworthy that these are only a few examples of the potential for SNA in the investigation of the interlocks. Other properties and metrics can be evaluated, compared, and/or used to analyze the effects of board diversity, Fiscal Council members' networks, or other aspects from emerging economies, as suggested by Smith and Sarabi (2021b).

Table 6. Steps summarized.

Step	Procedure
#Step1	Collecting data from FRE.
#Step2	Shortcut to select data by using .rds file available.
#Step3	Select info of boards and directors to conduct the research.
#Step4	Handling data ID and names.
#Step5	Handling data and few adjustments (check and create CPF codes).
#Step6	Creating the adjacency matrix and network graphs.
#Step7	Exporting the complete matrix to CSV format.
#Step8	Creating tables with network measures.
#Step9	Descriptive statistics.
#Step10	Graphs of network measures.

Note. This table sums up the steps taken in this tutorial.

ADVANTAGES AND LIMITATIONS OF THE METHOD

The procedure provided in this tutorial regarding data collection, treatment, and social network analysis offers several advantages over different and segregated procedures. First, data collection steps help researchers effectively use GetFREData (Perlin et al., 2018), selecting the necessary data and the period covered to conduct the research. Second, data treatment procedures bypass the reduced reliability problems created by data informed incorrectly by companies in the FRE. Third, all the steps required to conduct social network analysis regarding board interlocks are provided in this tutorial, making the process easier for all researchers to conduct and understand the networks formed between companies that share at least one director. Finally, the empirical illustration of all procedures has demonstrated its advantages by providing an integrated and automatic procedure for conducting the research. Before this, many steps were done separately and conducted mainly by hand.

Despite their advantages, for research into Brazilian public companies, these procedures have certain limitations that provide avenues for further methodological development. First, we provided only a few adjustments in name and CPF. Additional analyses could be done manually to check directors' names and CPFs, which could increase the number of observations. Moreover, as companies inform the data without any filling pattern, it becomes hard to map all the necessary procedures in order to guarantee complete reliability. Second, in our social network analysis steps, we have shown only some social network measures. For future research, there exists the opportunity to conduct a more in-depth analysis, draft out the steps and procedures to map out different networks, and include different network measurements, such as transitivity (Borgatti, 2009).

CONCLUDING REMARKS

The purpose of this tutorial article is to help researchers conduct their research regarding social network analysis, in particular board interlocks. To make this possible, we have provided a step-by-step procedure to conduct data collection and data treatment. In addition, we showed the steps for building the adjacency matrix, generating and analyzing some network measurements and sociograms using R Studio.

To illustrate the process, we used a dataset with the board of directors' composition of Brazilian public companies covering the years 2019 and 2020. We also analyzed network measurements to show how they can be interpreted in this field of research. Furthermore, these measurements can be used within the econometric models as variables in many studies to identify board interlock precedents or outcomes. Our tutorial has focused on networks formed between companies that share their directors.

Our main contribution to the proposition of this tutorial lies in providing a guideline so that future research can be performed easily. Our primary goal has been to improve data reliability and orient researchers in the procedures to be conducted as well as automate most of the tasks that would be done by hand, subsequently reducing the time spent treating and handling the dataset. Doing so, we believe this tutorial can contribute to the enhancing of social network studies considering the Brazilian environment, increasing the understanding of board interlocks in an emergent country. Santos, Silveira, and Barros (2007) have shown that interlocks have been frequent in Brazilian publicly companies and that "larger boards, more dispersed ownership structures, and larger firm size are factors associated with higher level of board interlocking" (Santos, Silveira, & Barros, 2007, p. 126). However, quite a few studies have encompassed the understanding of board interlocks' inputs and outcomes in the Brazilian context. Besides that, this tutorial contributes to the literature by providing a practical methodology to measure corporate governance indicators that can be related to the currently relevant ESG agenda. Our tutorial may help researchers analyze, for example, the impact of board connections on ESG outcomes, such as board diversity and CEO compensation.

Some avenues for future research using the procedures described in this tutorial can be followed. Lamb and Roundy (2016) suggest some research opportunities encompassing board interlocks, such as an evaluation of interlocks between firms from different countries, an understanding of board interlock formation pattern (as firm age, for example), and the relationships between interlocks and entrepreneurship. Likewise, Sarabi and Smith (2021) suggest that although there was an increase in the study of interlocked directors and its effects in recent years, the gender of the interlocked directors is often neglected by researchers. In this sense, there is an opportunity to deepen the knowledge of interlocks between women directors and how it impacts firms' strategy and decisions.

Additionally, this model is focused primarily on how to collect and handle Brazilian publicly companies' dataset to be able to conduct social network analysis on board interlocks. Although it can be adapted to be applied in different fields of studies, we acknowledge that all models have restrictions and researchers can face necessity of adaptations to apply these instructions in other contexts.

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1st author: conceptualization (equal), data curation (lead), methodology (lead), visualization (lead), writing – original draft (lead), writing – review & editing (equal).

2nd author: conceptualization (equal), data curation (equal), validation (equal), visualization (equal), writing – original draft (equal), writing – review & editing (equal).

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The authors claim that all data used in the research have been made publicly available through the Harvard Dataverse platform and can be accessed at:

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