Conspiracy of Corporate Networks in Corruption Scandals

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Corruption in public procurement transforms state institutions into private entities where public resources get diverted for the benefit of a few. On this matter, much of the discussion centers on the legal fulfillment of the procurement process, while there are fewer formal analyses related to the corporate features which are most likely to signal organized crime and corruption. The lack of systematic evidence on this subject has the potential to bias our understanding of corruption, making it overly focused on the public sector. Nevertheless, corruption scandals worldwide tell of the importance of taking a better look at the misuse and abuse of corporations for corrupt purposes. In this context, the research presented here seeks to contribute to the understanding of the criminal conspiracy of companies involved in public procurement corruption scandals under a network and complexity science perspective. To that end, we make use of a unique dataset of the corporate ownership and management information of four important and recently documented cases of corruption in Mexico, where hundreds of companies were used to embezzle billions of dollars. Under a bipartite network approach, we explore the relations between companies and their personnel (shareholders, legal representatives, administrators, and commissioners) in order to characterize their static and dynamic networked structure. In terms of organized crime and using different network properties, we describe how these companies connect with each other due to the existence of shared personnel with role multiplicity, leading to very different conspiracy networks. To best quantify this behavior, we introduce a heuristic network-based conspiracy indicator that together with other network metrics describes the differences and similarities among the networks associated with each corruption case. Finally, we discuss some public policy elements that might be needed to be considered in anti-corruption efforts related to corporate organized crime.

Keywords: corruption, conspiracy, corruption networks, social network analysis (SNA), complex networks, complex systems, social physics, legal studies

1 INTRODUCTION

Corruption is a complex adaptive problem that threatens the integrity of modern societies. According to the United Nations, corruption is a transnational phenomenon that affects all societies in deep and multiple ways, at their political, economic, ecological, and social fronts [1, 2]. This is especially harmful in developing countries where it links to other forms of crime, such as organized crime [3, 4], economic crime, and where, on top of that, delegation of authority takes place [5].

For many years, academic researchers have provided insight into the corruption phenomenon through multidisciplinary approaches [6, 7]. Under these approaches, corruption is broken down into various types of individual or collective behaviors within several processes that affect private and public sectors likewise. Notably, the procurement of goods, services, and works is one of the governments' activities most vulnerable to corruption, with complex processes and high level of interactions between public officials and private businesses [8]. Here, corruption transforms public state institutions into private entities where public resources get diverted for the benefit of a few. Many legal corruption types are common at all stages of the procurement process, such as embezzlement, bribery, conflict of interest, fraud, conspiracy, and the use of shell companies to alter competition, among others [3, 9]. For those reasons, governments lose a significant amount of funds in corrupt practices, and thus, purchasing is considered a high-risk activity [4, 9].

The vast academic literature on government procurement and auctions is continuously developing sophisticated analyses to tackle fraud schemes in all stages of the process, while there are fewer formal analyses related to linking corporate criminal activities to the ownership and management features and collective behaviors that are most likely to signal corruption regardless of the procurement method [10–12]. The lack of systematic evidence based on real activities on this subject has the potential to bias our understanding of corruption, making it overly focused on the public sector, ignoring the structural dynamics that take place in the ecosystem of private entities (bidders) [13]. This issue is mainly due to the poor access to widely reliable data on the private sector, specifically the management and ownership of companies. On the one hand, the abuse of private (shell) companies is a well-known phenomenon that is well documented in few cases, but most of the time, it requires extensive research on government records, long waiting periods after freedom of information act requests, and handcrafted processing of information afterward. On the other hand, companies involved or misused for corrupt purposes tend to hide or misinform about their management and ownership structure either by being registered off-shore or by using straw men. In the case of the latter, the multiplicity of personnel roles (shareholders, managers, or legal representatives) within or among companies creates unusual corporate profiles that are still far unexplored and that might provide further insight into potential criminal activity. Therefore, the analysis of corruption related to private companies, especially in developing countries' context, is a relevant aspect at the forefront of international anti-corruption efforts that requires formal and extensive research [13].

Recently, data-driven studies based on complex systems and network theory approaches have delved into the description of the network characteristics of real corporations at the level of board members [14] as well as those that have participated in big corruption scandals [15]. Under a complex systems perspective, corruption can be seen as an adaptive phenomenon that is best understood in terms of the collective behavior of interrelated agents acting as a whole; that is, it could be hypothesized that this phenomenon is dominated by network effects and thus best

characterized by unique collective properties that could provide more insight into corruption, organized crime, and cheating cases than by simply looking at isolated actors or events [12, 15–19]. Under this systemic perspective, the players are considered as connected actors on a network, regardless of their underlying interests or motivations, and the goal is to analyze the emerging structure, dynamics, organization, *modus operandi*, and the role that the actors play in practice as a collective. Linking actors by contracts, labor, or social relations may depict an organized network working for a common goal (win elections), multiple goals (private gain), or yielding criminal conspiracy (agreement to commit illegal acts) between companies bidding or having direct contracts while they intend to remain undetected and camouflage their activity. In public procurement, it is known that networked corruption schemes limit competition and affect the quality and efficacy of services, goods, and activities financed by governments [8, 10, 17]. However, to this day, there is no comprehensive understanding and convincing systematic evidence about the main structural and dynamical features of networked companies that might be able to define signs of corruption in organized crime activity despite the purchasing method.

In this context, the research presented here seeks to contribute to the understanding of the criminal conspiracy of companies involved in public procurement scandals under a network and complexity science perspective. In particular, due to the quality and scope of the data used, we focused on the collective features of the companies at the ownership and management levels in order to describe and identify structural and dynamical patterns that might be able to provide further insight into the corrupt schemes and nature of the cases. As stated above, the multiplicity of personnel roles within or among companies creates unusual corporate profiles that are still far unexplored and that might provide further insight into potential criminal activity. To that end, we make use of a unique microlevel corporate ownership and management dataset of four important and recently documented cases of corruption in Mexico, where hundreds of companies were used to embezzle billions of dollars. Under a bipartite network approach, we explore the relations between companies and their personnel (shareholders, legal representatives, administrators, and commissioners) in order to depict their network structure. Using diverse network metrics, we describe how these companies are not independent but connected with each other due to the existence of shared personnel with role multiplicity. To quantify this behavior, we introduce a heuristic network-based conspiracy indicator that together with other network metrics describes the differences and similarities among the networks associated with each corruption case. Finally, we discuss the advantages and shortcomings of data and network-based approaches, open research, and public policy elements that might need to be considered in anti-corruption efforts related to corporate organized crime.

1.1 Data and Methods

Important remark: The judicial and criminal investigation processes of some of the cases presented in this study are pending; therefore, the present analysis is only valid for

academic purposes. For privacy protection, we have held in anonymity all the information regarding the identification of the companies and associated people. The data analyzed during the current study are available online (see Data Availability).

1.1.1 Data

The data used in this study were first gathered by investigative journalists and members of a local citizen participation committee, and it is related to four corruption scandals in public procurement involving three local administrations and the national government in Mexico: Veracruz (Case 1), Puebla (Case 2), Guanajuato (Case 3), and the Federation (Case 4), respectively. A short description of each case is presented below.

In order to have quality datasets that would allow for consistent comparisons among cases, we manually curated and double-verified the original data by using fiscal and official procurement records (when available). In some cases, the information regarding the tendering process and awarded contracts was missing or incomplete. Consequently, having consistent and verified data at the level of contracting bodies, suppliers, or bidders for all scandals was not possible. For this reason, the commonly employed analysis of the procurement environment as a network that considers the connections between the contracting institutions and suppliers, either under a bipartite institution–supplier network or a firm–firm co-bidding network [8, 17, 20], was not possible. However, the information regarding the connections of public servants and business people to their corresponding institutions or companies, respectively (beyond hidden political ties), is an aspect that can be further explored. In particular, the multiplicity of personnel roles within or among companies creates unusual corporate profiles and networks at the level of the supplier's ecosystem that are still far unexplored and that might provide further insight into potential criminal activity. Therefore, we focused on the collective features of the companies at the ownership and management levels in order to describe and identify structural and dynamical patterns that might be able to provide further insight into the corrupt schemes and nature of the cases.

After curating and cross-validating the records, we came up with datasets that contain information regarding the four roles that comprise the ownership and management of the firms as they appear in the companies' charters and contracts: shareholders (SHs), administrators (ADMs), legal representatives (LRs), and commissioners (COMs). The date of creation of the companies as well as identifier of whether the company has been classified as shell by fiscal authorities are also provided (more details in the data repository; see Data Availability).

The cases presented in this research fall into a certain type of procurement practices within an environment that deems common in Mexico. Since 2013, the tendency in federal public spending has increasingly turned over the direct contracting and restricted invitations, in substitute to the bidding procedures, to the point that by 2020, over 80 percent of the federal government contracts were directly awarded to companies [21]. This tendency replicates within the states, where heterogeneous legislation often allows budget thresholds to be exceeded, requires fewer requisites

for tenders, and not all state governments make calcification and on-site visits [22]. As a consequence of this high-risk corruption context, market concentration and the creation of short-term companies that can offer multiple products and services prevail in the county. When federal or state public officials and private actors bypass legislation to obtain private gain (a corruption or criminal goal), they use companies (existing and new) to divert resources. Many of those companies become listed as shell given tax offenses within the course of three years [23]. Specifically, within the four cases selected for this study, nonstandard practices are often in place, such as bid-rigging, communication between companies during tender process, increased input costs and contract prices, and high degree of discretion of public servants in the application of the public procurement regulatory framework.

These four cases are selected for the following reasons: data availability, the governments assigned contracts to a set of companies that later were prosecuted by fiscal authorities and finally enlisted as shells, and these cases portrayed a great number of companies and personnel involved. Corruption in the cases presumably happened when companies failed to comply with the contracts, diverted public goods, product substitution, and/or simulated operations under Mexican fiscal legislation in order to commit embezzlement, fraud, and money laundering. The data used in the study imply certain limitations. Since most of the information is public or was made public after freedom of information requests, it is possible that governments answered in a restrained fashion, discarding documents and contracts that also relate to the network's or cartels' activities. Also, the contracts analyzed for the study contain straw men, criminal impersonation, and inauthentic companies' address, due to the criminal activities undertaken. And finally, the contract samples are not the result of statistical methods, but a selection of corruption media scandals set by a journalistic narrative; therefore, criminal files may or may not correspond to the grouping of participants. Although the data of the cases do not represent a large-scale sample of the procurement environment, other studies have used media corruption scandals based on government information to describe network structure and dynamics over the time [16, 24]. Hence, the results are not applicable to all procurement environments, but only to procurement and direct contracts activities that have been flagged by the fiscal and prosecution authorities, and where information is publicly available after corruption activity or the use of shell companies has been detected.

A shell company is commonly defined as an entity legally incorporated that, structurally speaking, lacks substantial assets, operations, or even employees, and when used for illicit purposes, the entity is typically oriented to the concealment of beneficial ownership. Likewise, it is characterized by the appointment of informal nominees, such as children, spouses, relatives, or associates who do not appear to be involved in the running of the corporate enterprise [25]. According to Mexican fiscal law, shell companies are categorized as such based on the government registry of tax evasion that is publicly available, when there is missing or in existent address, simulated operations, inauthentic

documentation, lack of assets, or issue fiscal receipts to feign operations. Mexican fiscal authorities list them after an investigation that could take months or years after they were established.

Case 1-Veracruz: The data of this case were originally gathered from governmental sources (open to public access under Mexico's General Law of Transparency and Access to Information and local transparency legislation) by the nongovernmental organization known as Mexicanos Contra la Corrupción e Impunidad (Mexicans Against Corruption and Impunity) and the investigative journalism group known as Animal Político in 2016 [23]. Journalists also undertook field trips to verify shell companies' addresses. These companies participated in bidding procedures and direct award. At least four state government agencies contracted the group of companies and have been prosecuted for diverting public funds, amounting over 30 million of U.S. dollars between the years 2012 and 2014 [23]. Unlike the other three cases selected for this study, the procurement environment and legal framework in Veracruz favor an array of concentration practices. Although the end recipients of the funds are unclear, the journalist group has reasons to believe that resources were diverted to the political campaign for the national presidency held in 2012. This would explain the participation of a larger number of companies and collaborating under a meticulous design of fraud scheme for over 3 years. The corruption schemes under investigation by the fiscal authorities consisted in the use of straw men, other fiscal offenses, and tax fraud to divert public funds through tenders. In this scandal, there are 354 companies (96 of which are shell) and 306 personnel (or people) associated with those companies.

Case 2-Puebla: The contracts sampled for this case date from 2015 to 2018 where the state and municipal government of Puebla contracted services and goods from companies that were mostly listed as shell by the national fiscal authority. In total, the companies developed contracts over 17 million dollars. The research was made by journalism group *Datamos*, in coordination with the International Center for Journalists and Connectas [26]. The collection of data methods included filing of freedom of information requests under state legislation and from official websites available by legal transparency mandate (*Plataforma Nacional de Transparencia* and *Compranet*). In addition, journalists undertook field trips to verify shell companies' addresses and also interview several companies' stakeholders and public officials to validate data. The contracted companies were founded during the years 2012–2015, and three years later, 68 companies were listed as shell companies by the tax federal authority *Servicio de Administración Tributaria*. At least eleven state and municipal agencies contracted the companies from the sectors of education, infrastructure, health, security, and others. The corruption scheme under investigation by the fiscal authorities consisted in the use of straw men, other fiscal offenses, and tax fraud to divert public funds through tenders. In this scandal, there are 90 companies (87 of which are shell) and 230 personnel associated with those companies.

Case 3-Guanajuato: The data sample comprises the state and municipal governments of Guanajuato. The contracts were assigned to companies that have been listed as shell by the federal fiscal authority during the years 2014–2019. The source of this information is a special report of the Citizenship Committee of the State's Anti-corruption System, an official agency created by the anti-corruption state law with oversight powers. The committee filed numerous freedom of information requests and appeals to gather the data of the contracts with the state government, 4 municipalities, the state university, and other agencies. The report aimed to evaluate the state's situation regarding simulated operations and to track public funding diverted to shell companies for over 9 million U.S. dollars [27, 28]. In this case, the corruption scheme under investigation by the fiscal authorities also consisted in the use of straw men, other fiscal offenses, and tax fraud to divert public funds through tenders. There are 110 companies (101 of which are shell) and 511 personnel associated with those companies.

Case 4-Federation: The case was known in the media as the "Master Fraud" (*Estafa Maestra*) where federal and six state governments channeled public resources to regular and shell companies through state universities. The data were originally gathered from official sources and websites under Mexico's General Law of Transparency and Access to Information by the nongovernmental organization *Mexicanos Contra la Corrupción e Impunidad* (Mexicans Against Corruption and Impunity) and the investigative journalism group known as *Animal Político* [29]. The case sample was made after the general audit authority reviewed the contracts and identified possible fraud, embezzlement, money laundry, and misuse of public resources between the years 2013–2014 for over 380 million dollars. In this case, the government funds were diverted through contracts with public universities that hired shell companies to develop projects and activities, in which the general audit authority identified illegal contracts, fiscal offenses, and tax fraud in tenders. There are 120 companies (51 of which are shell) and 446 personnel associated with those companies.

2 METHODS

In this study, *criminal conspiracy* is seen as an organized crime act or as "an agreement between two or more people to commit an illegal act, along with an intent to achieve the agreement's goal" (e.g., see Whitfield v. United States, 453 U.S. 209 (2005)). Despite not having real evidence that the companies communicated previously or during the government purchases, we hypothesize that the emergence of networked structures due to the existence of shared personnel among companies represents a relevant proxy to the level of conspiracy of the actors involved; that is, if conspiracy is present, then it is encoded in the structure of the corporate networks.

We consider this a valid hypothesis in the context of the procurement corruption scandals studied here, where the corporate ownership and management information is not readily available or even not existent, and true ownership can be easily concealed. In this scenario, the abuse and misuse of small-size corporations is easily done by (although not restricted to), for example, the use of multiple straw men. Therefore, if

conspiracy is encoded in networked structures of companies with shared personnel, network analysis will allow us to identify and quantify the static and dynamic network properties that might be able to signal organized crime and corruption [15, 16].

Under the previous considerations, our analysis is divided into three parts: I) an elemental statistical description of some quantities related to the companies and personnel per case, II) an analysis of the relationships among companies and individuals under a bipartite network analysis perspective, and III) an analysis based on a heuristic conspiracy indicator that together with other network metrics is able to classify and quantify different levels of conspiracy. Below, we present the elements considered for each part of the analysis.

Part I-Elemental corporate features: For each case, the exploratory analysis considers the following basic variables:

- Total number of companies, N_{CO}.
- Total number of personnel, N_{PE}.
- Number of companies created per year, $n_{CO,t}$.
- Number of new personnel added per year, $n_{PE,t}$.
- Number of personnel per role (SHs, ADMs, COMs, and LRs).
- Number of role pairs (these are the number of individuals that fall within the intersection of any role pairs).
- Number of personnel per number of roles performed.

Part II-Bipartite networks: Given the nature of the data, we considered an undirected weighted bipartite network approach in which companies and individuals represent two different sets of nodes that are connected by four types of edges (SHs, ADMs, COMs, and LRs), and where the weight of the edges is given by the number of roles an individual performs within a company. The network properties we considered are as follows [30]:

- Density, $\delta = L/L_{max}$, where L is the number of observed edges and L_{max} is the maximum number of edges for a network of N nodes. For a bipartite network, $L_{max} = N_1 N_2$; thus,

$$\delta = \frac{L}{N_1 N_2}, \tag{1}$$

where $N_1 = N_{CO}$ and $N_1 = N_{PE}$.

- Mean degree, $\langle k \rangle$:

$$\langle k \rangle = \frac{1}{N} \sum_{i=1}^{N} k_i, \tag{2}$$

where k_i is the degree of the ith node and N is the number of nodes of the corresponding set.

- Mean weighted degree or *strength*, $\langle s \rangle$:

$$\langle s \rangle = \frac{1}{N} \sum_{i=1}^{N} s_i; \; s_i = \sum_{j} w_{ij}, \tag{3}$$

where w_j is the weight of the edges between the ith and jth nodes, and N is the number of nodes of the corresponding set.

- Clustering coefficient of Robins–Alexander, C_{RA}. For a bipartite network, Robins and Alexander [31] defined the bipartite clustering coefficient as four times the number of four cycles, C_4, divided by the number of three paths, L_3, that is:

$$C_{RA} = \frac{4C_4}{L_3}. \tag{4}$$

- Number of connected components, N_{CC}. A connected component is a subnetwork containing one or more nodes such that there is a path connecting any pair of these nodes, but there is no path connecting them to other components.

Part III-Conspiracy indicator: According to our hypothesis—if conspiracy is present, then it is encoded in the network structure of companies with shared personnel—one straightforward measure of the conspiracy levels of a given set of companies is the ratio of connected components N_{CC} relative to the total number of companies N_{CO}. Under this consideration, the mathematical details of the indicator will be shown in the corresponding Results section.
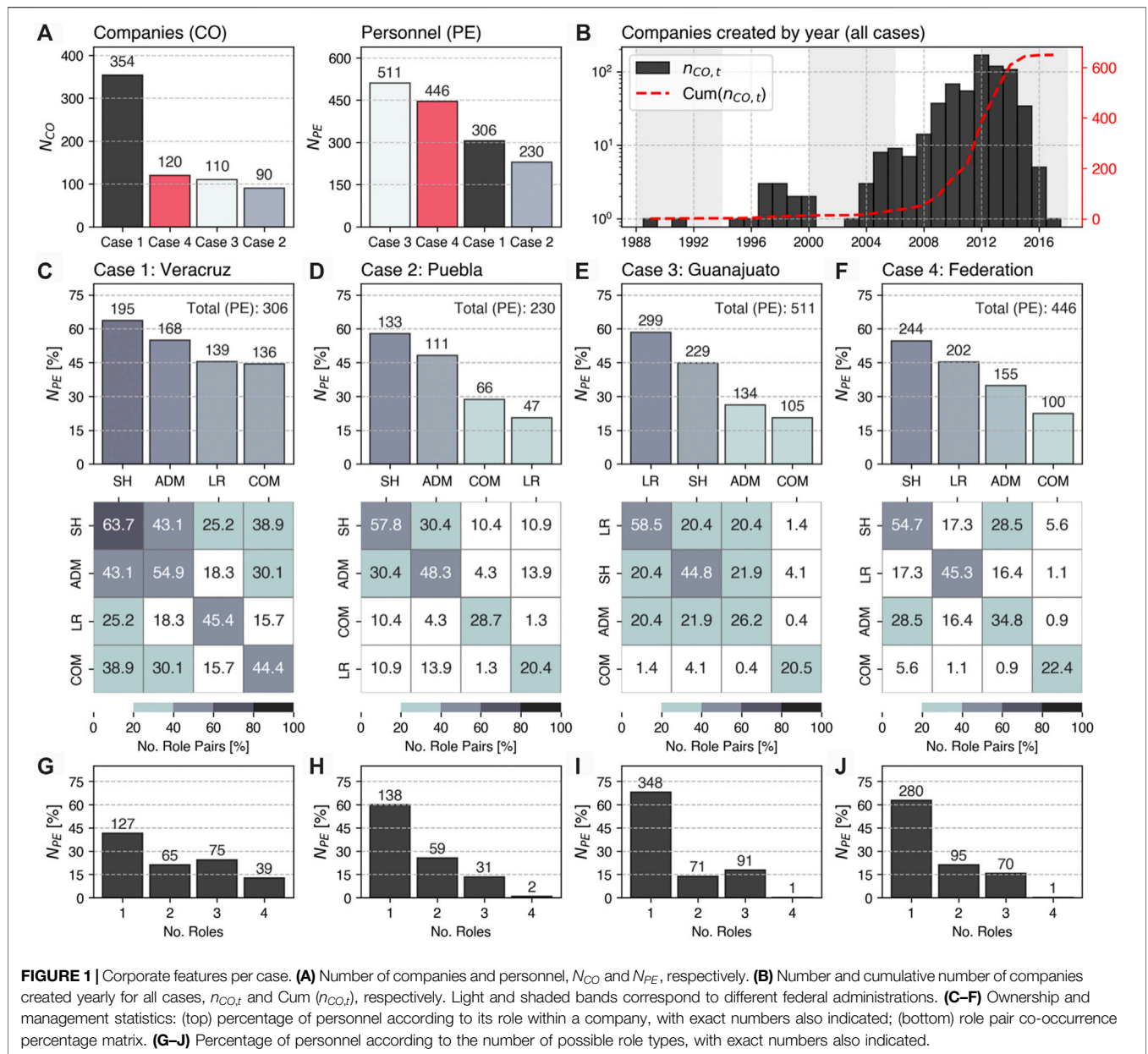
All analyses were done using custom Python code. The network metrics were computed using the Python's NetworkX package [32]. The network visualizations were created using Cytoscape [33].

3 RESULTS

3.1 Part I-Elemental Corporate Features

The main results for the first part of our analysis are presented in **Figures 1**, **2**.

In **Figure 1A**, we show the total number of companies, N_{CO}, and personnel, N_{PE}, per case. In **Figure 1B**, we show the total number and cumulative number of companies created per year for all cases, $n_{CO,t}$. This provides an overall perspective of the temporal scale of action that spans several federal administrations (as indicated with light and shaded regions) and the dynamics of the companies' creation rate that spikes in recent years, with the cumulative number of companies indicating that around 2012, we got approximately 50% of all the companies. This is further explored in **Figures 2A–D**, where we present: (first row) the number and cumulative percentage of companies created per year, respectively, (second row) number and cumulative percentage of new personnel per year, respectively, and (third row) cumulative number of companies and personnel per year. Light and shaded regions indicate the changes in the local or

FIGURE 1 | Corporate features per case. **(A)** Number of companies and personnel, N_{CO} and N_{PE}, respectively. **(B)** Number and cumulative number of companies created yearly for all cases, $n_{CO,t}$ and Cum $(n_{CO,t})$, respectively. Light and shaded bands correspond to different federal administrations. **(C–F)** Ownership and management statistics: (top) percentage of personnel according to its role within a company, with exact numbers also indicated; (bottom) role pair co-occurrence percentage matrix. **(G–J)** Percentage of personnel according to the number of possible role types, with exact numbers also indicated.

federal government administrations accordingly. In particular, notice how the rate of creation of companies is always below the rate of addition of new personnel, except for Case 1.

In **Figures 1C–F**, we present some ownership and management statistics. First (top of the panel), we show the percentage of personnel according to its role within a company (SHs, ADMs, COMs, and LRs), with exact numbers indicated. Here, it is observed that the most prominent role is the one of shareholder (SH), followed by administrator (ADM) and legal representative (LR), and last, commissioner (COM). Second (bottom of the panel), we show the role-pairs in the form of a co-occurrence percentage matrix. The diagonal reproduces the distribution on top, while off-diagonal elements are associated with the percentage of individuals that fall within the intersection

of any role-pairs. The most prominent role-pair is SH–ADM, which in all cases shows up above 20%, followed by SH–LR and ADM–LR that fall closely below 20%. Commissaries seem to be the least important actors as seen for Cases 2–4; however, they recover an important role for Case 1, where the different types of roles are highly connected, indicating a high degree of role multiplicity. This is even clearer in **Figures 1G–J**, where, in correspondence with the previous panel, we show the personnel profiles according to the number of roles performed. For Cases 2–4, most people (around 60%) perform just one role, while four roles is the least likely profile to be observed. However, Case 1 displays a maximum number of these very unlikely four-role profiles and the least percentage of one-role individuals.
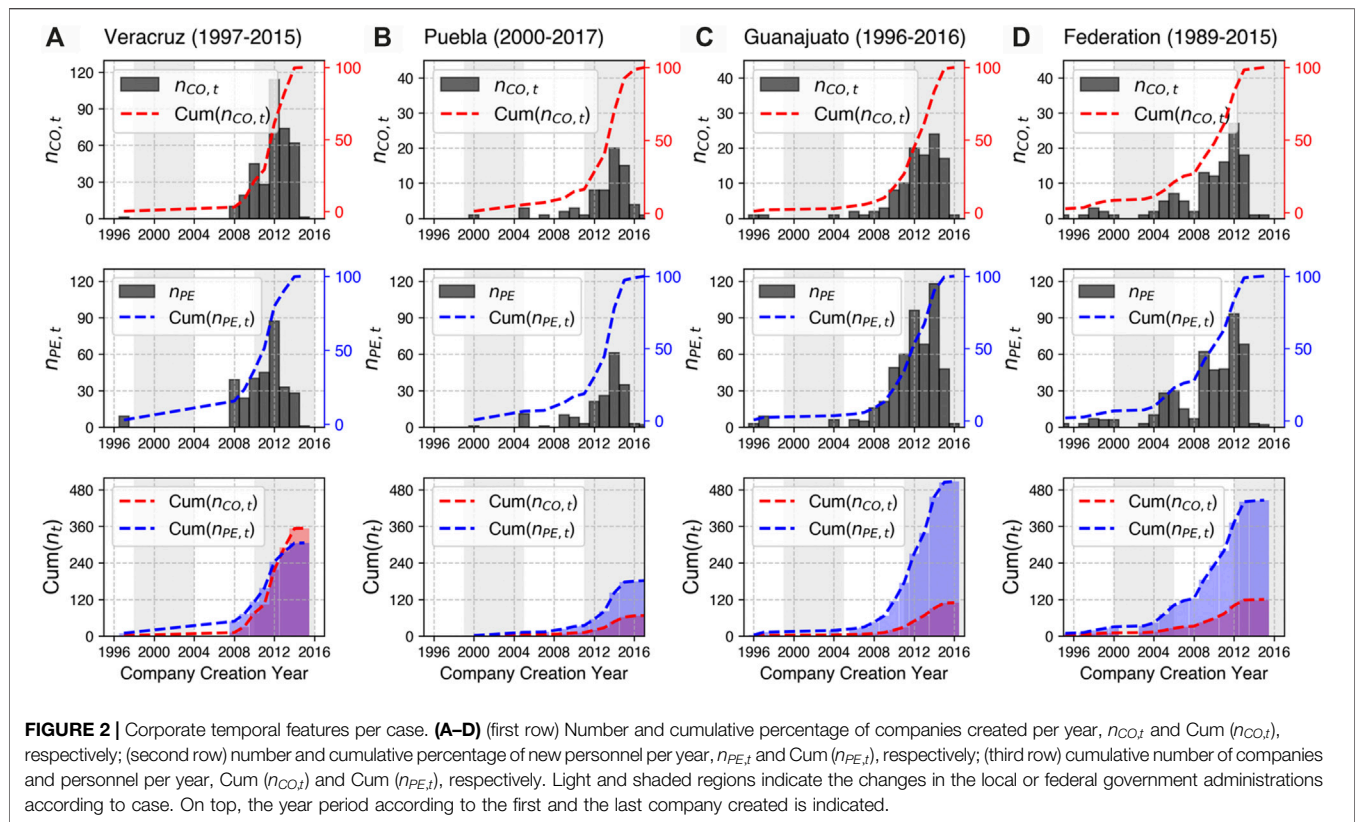
FIGURE 2 | Corporate temporal features per case. **(A–D)** (first row) Number and cumulative percentage of companies created per year, $n_{CO,t}$ and Cum $(n_{CO,t})$, respectively; (second row) number and cumulative percentage of new personnel per year, $n_{PE,t}$ and Cum $(n_{PE,t})$, respectively; (third row) cumulative number of companies and personnel per year, Cum $(n_{CO,t})$ and Cum $(n_{PE,t})$, respectively. Light and shaded regions indicate the changes in the local or federal government administrations according to case. On top, the year period according to the first and the last company created is indicated.

As observed in this part of the analysis, although Cases 2–4 vary in the number of companies and personnel, they share common properties regarding the distribution of role-pairs, role profiles, and temporal dynamics. Case 1 clearly presents an anomalous behavior that deviates from the rest.

3.1.1 Part II-Bipartite Networks

The main results for the second part of our analysis are presented in **Figures 3**, **4**.
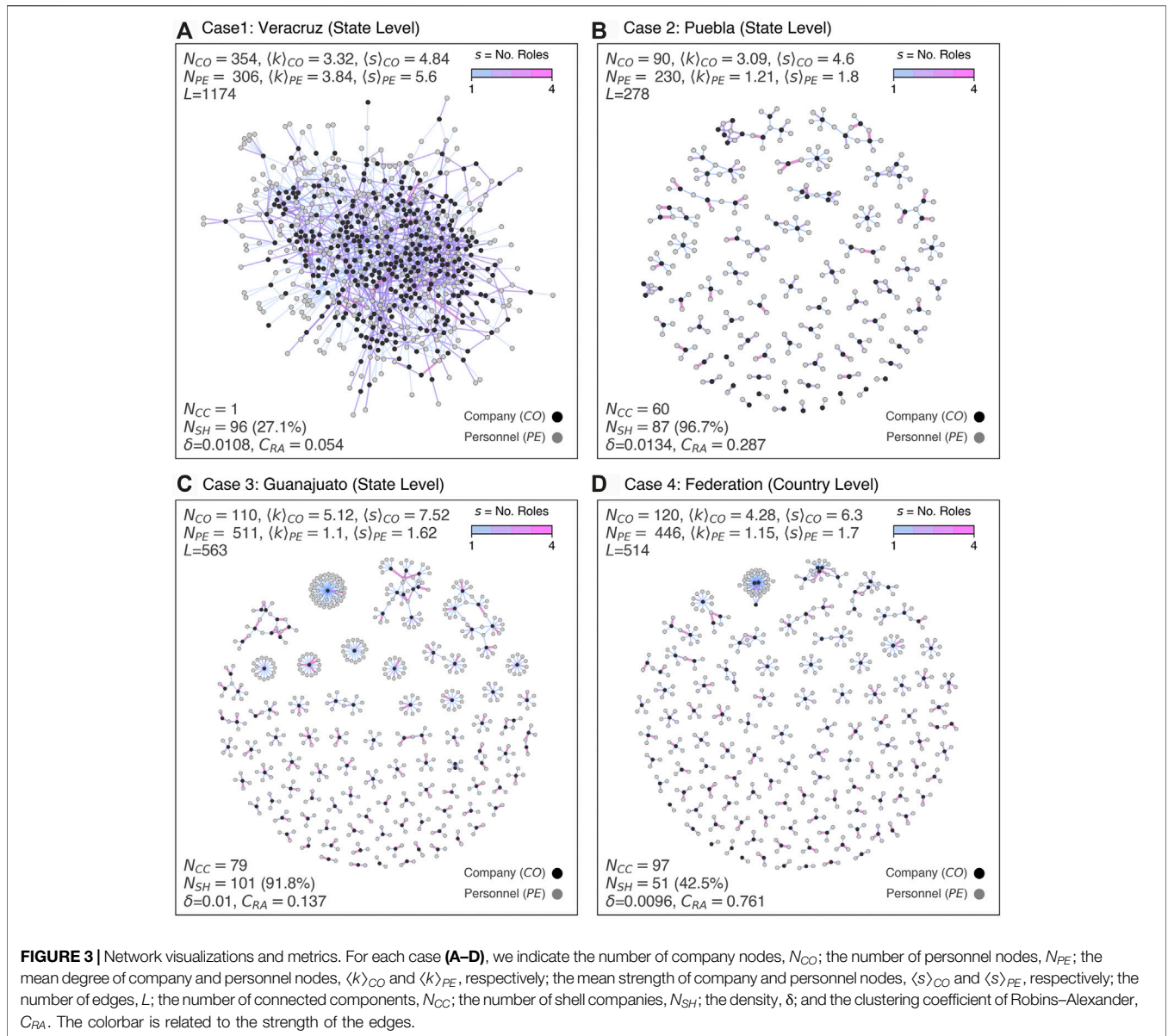
In **Figure 3**, we show the network visualizations and some network metrics: Case 1 (Veracruz), **Figure 3A**; Case 2 (Puebla), **Figure 3B**; Case 3 (Guanajuato), **Figure 3C**; and Case 4 (Federation), **Figure 3D**. For each case, we indicate the number of company nodes, N_{CO}; the number of personnel nodes, N_{PE}; the mean degree of company and personnel nodes, $\langle k \rangle_{CO}$ and $\langle k \rangle_{PE}$, respectively; the mean strength of company and personnel nodes, $\langle s \rangle_{CO}$ and $\langle s \rangle_{PE}$, respectively; the number of edges, L; the number of connected components, N_{CC}; the number of shell companies, N_{SH}; the density, δ; and the clustering coefficient of Robins–Alexander, C_{RA}.

We found a remarkable difference in the network connectivity among cases, with Case 1 being the only one forming one giant connected component, while Cases 2–4 show very similar sparsity, although the density (given by **Eq. 1**) is quite similar for all cases, with $\delta \approx 0.01$. Another relevant difference was found in the values of the clustering coefficient of Robins–Alexander, C_{RA} (given by **Eq. 4**), for whose, the maximum value is associated with Case 4, $C_{RA} = 0.761$, while the minimum value is associated

with Case 1, $C_{RA} = 0.05$. This counterintuitive result can be understood in terms of the definition of C_{RA}, in which only four cycles, C_4, are counted. Thus, the C_4 property is found in a great number of connected components in Cases 2–4 than in Case 1, for which this interpretation leads to the conclusion that companies and people tend to form more cycles of greater size or even chains than closely connected clusters.

In the case of the mean degree, $\langle k \rangle$, we found that there are important differences according to the node type. For the companies, $\langle k \rangle_{CO}$ represents their average number of personnel. We found that $3.09 \leq \langle k \rangle_{CO} \leq 5.12$, indicating the small size of the companies on average, with Case 3 being the one with the greatest corporate mean degree. For the personnel, $\langle k \rangle_{PE}$ represents their average number of associated companies. We found that $1.10 \leq \langle k \rangle_{PE} \leq 3.84$. In particular, the personnel mean degree of Cases 2–4 is quite similar, $\langle k \rangle_{PE} \approx 1$, while the one for Case 1 is $\langle k \rangle_{PE} \approx 4$, both in direct correspondence with the observed connectivity in **Figure 3**.

The mean strength, $\langle s \rangle$, is best understood in conjunction with the mean degree, $\langle k \rangle$. Specifically, the difference between the mean strength and mean degree, $\langle s \rangle - \langle k \rangle$, is a measure of the average role multiplicity in a corporate network. For example, given a corporate network for which $\langle k \rangle = 3$ and $\langle s \rangle = 5$ (either for the companies or the personnel), $\langle s \rangle - \langle k \rangle = 2$ implies that, on average, two out of three edges have a strength of two, indicating role multiplicity. Therefore, the greater the difference between the mean strength and the mean degree, the greater the multiplicity of roles in a corporate network.
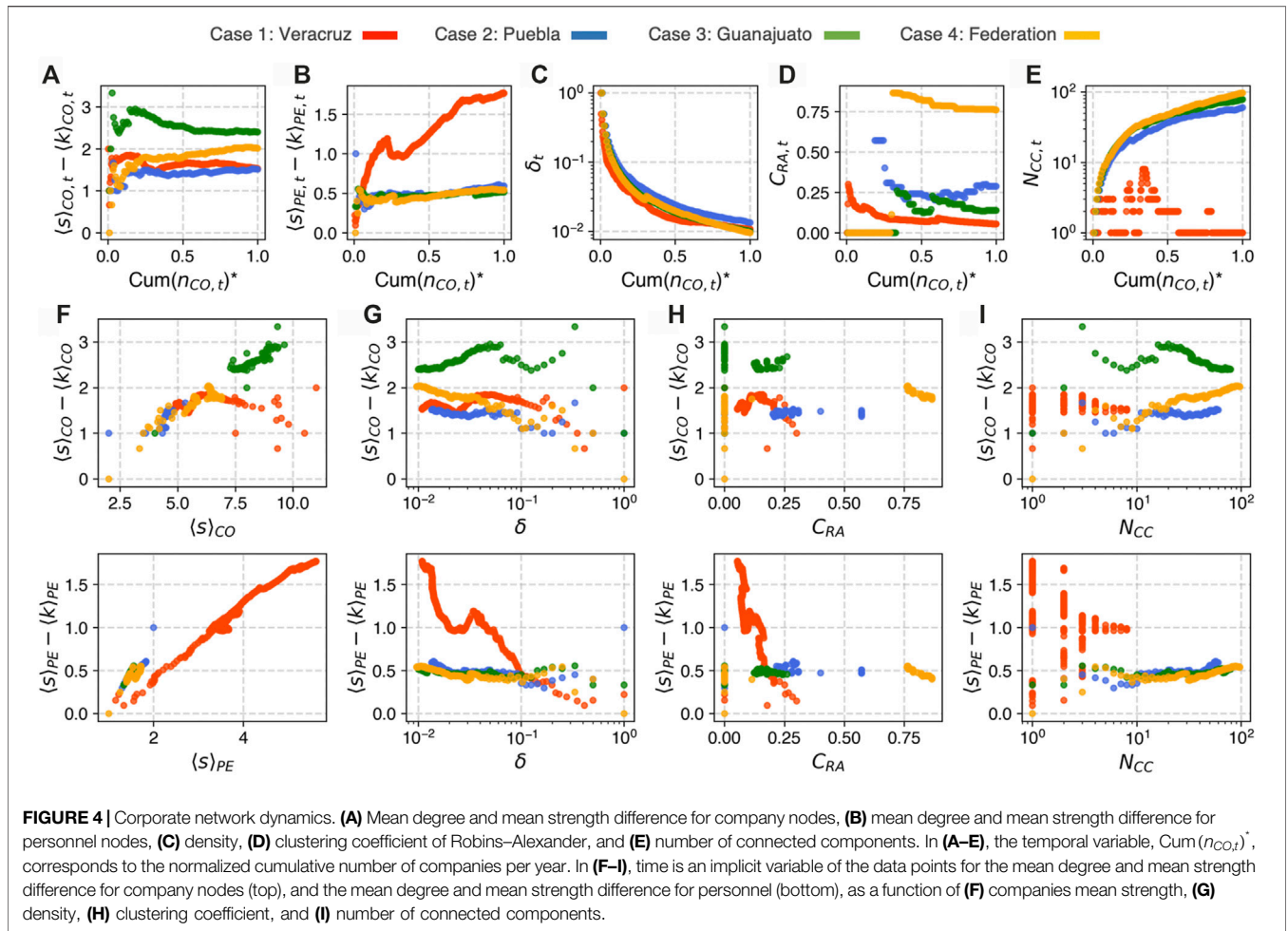
FIGURE 3 | Network visualizations and metrics. For each case **(A–D)**, we indicate the number of company nodes, N_{CO}; the number of personnel nodes, N_{PE}; the mean degree of company and personnel nodes, $\langle k \rangle_{CO}$ and $\langle k \rangle_{PE}$, respectively; the mean strength of company and personnel nodes, $\langle s \rangle_{CO}$ and $\langle s \rangle_{PE}$, respectively; the number of edges, L; the number of connected components, N_{CC}; the number of shell companies, N_{SH}; the density, δ; and the clustering coefficient of Robins–Alexander, C_{RA}. The colorbar is related to the strength of the edges.

Notably, the differences and similarities previously described are best appreciated by looking at the evolution of these quantities in time. In **Figure 4**, we present a comparative corporate network dynamics for all cases with respect to different network metrics. As the time variable, we consider the normalized cumulative number of companies per year, $\text{Cum}(n_{CO,t})^* \in [0, 1]$.

In **Figure 4A**, we show the mean degree and mean strength difference for company-type nodes (or the average role multiplicity in a company) as time progresses. Remarkably, Case 1 mimics Case 2 and Case 4 at initial stages; however, the latter has higher values and a different behavior (steeper slope) than the former one. The higher values of Case 3 indicate that, on average, companies tend to have personnel with higher role multiplicity. In **Figure 4B**, we show the mean degree and mean strength difference for personnel-type nodes (or the average role multiplicity of an individual). Remarkably, Cases

2–4 display identical (almost constant steady) dynamics, while Case 1 clearly differentiates from the rest, indicating a highly irregular increase in the role multiplicity of individuals as time progresses.

The previous observations regarding Case 1 can be complemented and best understood by comparing them with the cumulative number of companies, $\text{Cum}(n_{CO,t})$, and the cumulative number of new personnel, $\text{Cum}(n_{PE,t})$, per year (see **Figure 2**). For Cases 2–4, we have that the inequality $\text{Cum}(n_{CO,t}) < \text{Cum}(n_{PE,t})$ is always satisfied, indicating that companies and new personnel with same role multiplicity are added in the same proportion per year, while for Case 1, we have that the inequality is not always satisfied, indicating that companies and personnel are added at a disproportionate rate ($\text{Cum}(n_{CO,t}) > \text{Cum}(n_{PE,t})$) in which the same personnel is used in multiple roles for multiple companies.

FIGURE 4 | Corporate network dynamics. **(A)** Mean degree and mean strength difference for company nodes, **(B)** mean degree and mean strength difference for personnel nodes, **(C)** density, **(D)** clustering coefficient of Robins–Alexander, and **(E)** number of connected components. In **(A–E)**, the temporal variable, $\text{Cum}(n_{CO,t})^*$, corresponds to the normalized cumulative number of companies per year. In **(F–I)**, time is an implicit variable of the data points for the mean degree and mean strength difference for company nodes (top), and the mean degree and mean strength difference for personnel (bottom), as a function of **(F)** companies mean strength, **(G)** density, **(H)** clustering coefficient, and **(I)** number of connected components.

In **Figure 4C**, we show the dynamics of the density, which is almost identical for all cases; in **Figure 4D**, we show the clustering coefficient of Robins–Alexander, which presents different dynamics for each case, with Case 1 and Case 4 being clearly differentiated at all times, while Cases 2 and 3 only for their later years; in **Figures 4D,E**, we show the number of connected components. Notably, Cases 2–4 display the same dynamics in their formation of connected components, while Case 1 is completely anomalous.

In **Figures 4F–I**, we present a comparative analysis for both role multiplicity indicators, $\langle s \rangle_{CO} - \langle k \rangle_{CO}$ and $\langle s \rangle_{PE} - \langle k \rangle_{PE}$, in which we display them as a function of the company's mean strength, the density, the clustering coefficient, and the number of connected components, respectively. Here, time is an implicit variable of the data points.

The results presented in this part of our analysis show that network science is a powerful analytical framework that is able to provide a deeper insight into the static and dynamical features of the cases studied. In particular, they clearly highlight Case 1 as a very irregular event compared even with other corruption cases. However, when it comes to having a better measure of the conspiracy levels for each case, it is hard to identify the set of network metrics that might be able to provide that description.

3.1.2 Part III-Conspiracy Indicator

According to our hypothesis—if conspiracy is present, then it is encoded in the network structure of companies with shared personnel—one straightforward measure of the conspiracy levels of a given set of companies is the ratio of connected components, N_{CC}, relative to the total number of companies, N_{CO}, that is,

$$\phi_C = 1 - \frac{N_{CC}}{N_{CO}}, \tag{5}$$

where $N_{CC} \in [1, N_{CO}]$. The minimum value, ϕ_C^{min}, is given when $N_{CC} = N_{CO}$, at which $\phi_C^{min} = 0$, indicating that all companies are disconnected (no conspiracy). Its maximum value, ϕ_C^{max}, is given when $N_{CC} = 1$, indicating that all companies are connected into one giant component (maximum conspiracy levels). In this case,

$$\phi_C^{max} = 1 - \frac{1}{N_{CO}}. \tag{6}$$

Notice that both ϕ_C and ϕ_C^{max} are dependent on N_{CO} and well defined for finite or small-size networks. Therefore, the distance to maximum conspiracy would simply be
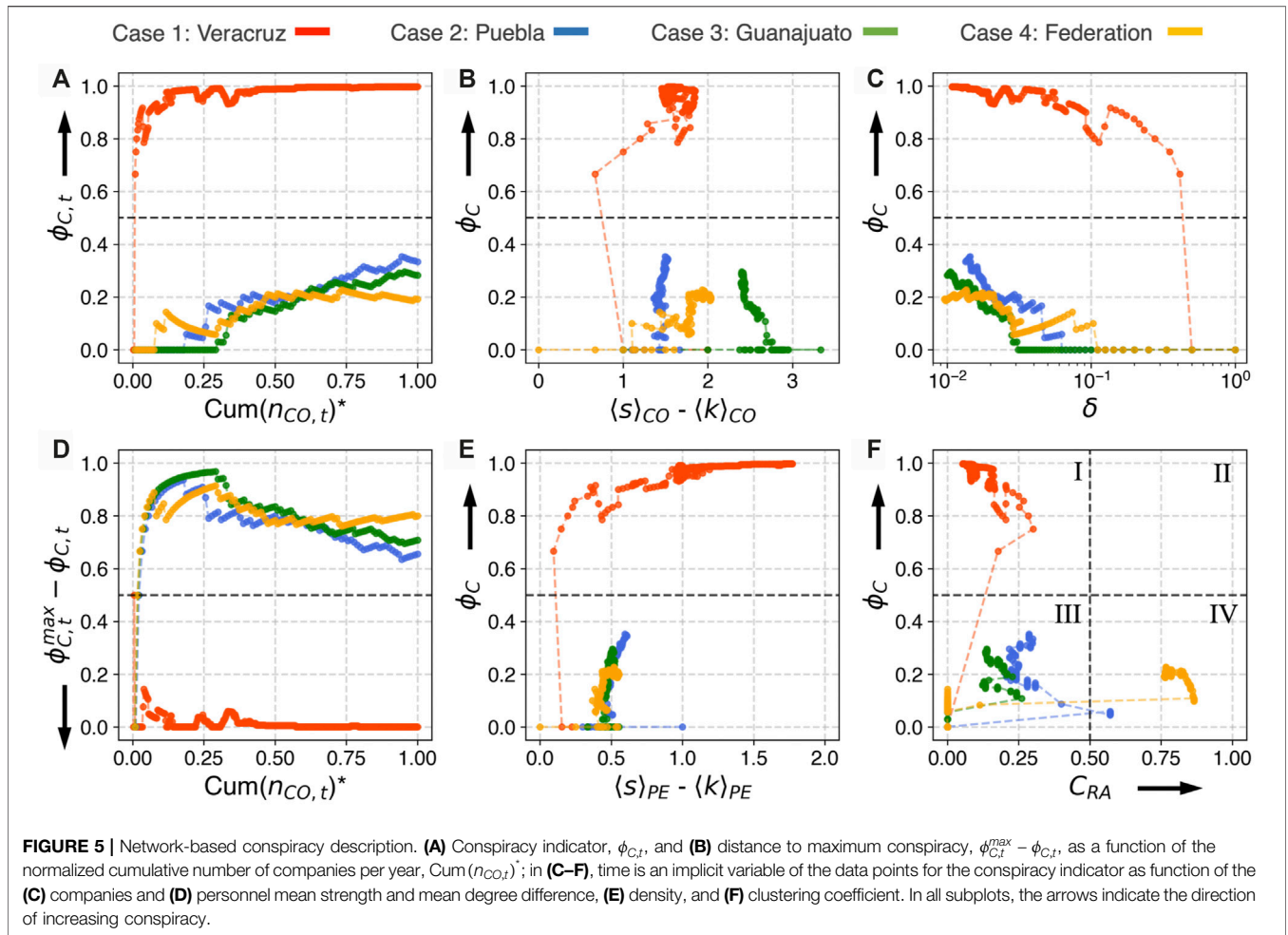
FIGURE 5 | Network-based conspiracy description. **(A)** Conspiracy indicator, $\phi_{C,t}$, and **(B)** distance to maximum conspiracy, $\phi_{C,t}^{max} - \phi_{C,t}$, as a function of the normalized cumulative number of companies per year, $\mathrm{Cum}(n_{CO,t})^*$; in **(C–F)**, time is an implicit variable of the data points for the conspiracy indicator as function of the **(C)** companies and **(D)** personnel mean strength and mean degree difference, **(E)** density, and **(F)** clustering coefficient. In all subplots, the arrows indicate the direction of increasing conspiracy.

$$\Delta\phi_C = \phi_C^{max} - \phi_C = \frac{N_{CC} - 1}{N_{CO}}. \qquad (7)$$

Here, when $N_{CC} = 1$, it implies maximum conspiracy, while for $N_{CC} = N_{CO}$, it recovers ϕ_C^{max}.

In **Figure 5**, we present our description based on the conspiracy indicator ϕ_C given by **Eq. 5**. In **Figure 5A**, we show its temporal evolution as a function of the normalized cumulative number of companies per year, $\mathrm{Cum}(n_{CO,t})^* \in [0, 1]$. In **Figure 5B**, we show its dynamical evolution relative to the maximum conspiracy indicator given by **Eqs. 6, 7**. In both figures, a clear distinction can be observed among Case 1 and Cases 2–4. In **Figures 5C,D**, we show its behavior with respect to the role multiplicity indicators $\langle s \rangle_{CO} - \langle k \rangle_{CO}$ and $\langle s \rangle_{PE} - \langle k \rangle_{PE}$, respectively. In **Figure 5E**, we compare it to the density. In **Figures 5C–E**, a clear distinction can again be observed among Case 1 and Cases 2–4 with respect to ϕ_C.

Finally, in **Figure 5F**, we show its behavior with respect to the clustering coefficient of Robins–Alexander. Considering that both quantities are bounded, $\phi_C \in [0, 1]$ and $C_{RA} \in [0, 1]$, the plane could be divided into the indicated quadrants or regions I–IV, with each one providing a qualitative description for each case in terms of the number of connected components

information, given by ϕ_C, and the clustering, C_{RA}. In this way, Case 1 evolves in time toward the low clustering and high conspiracy region I, Cases 2 and 3 remain within the low clustering and low conspiracy region III, and Case 4 falls into the high clustering and low conspiracy region IV. Remarkably, the way each case is differentiated in terms of conspiracy-clustering regions is in an interesting correspondence with the general features of each corruption scandal, as it is discussed in the following section.

4 DISCUSSION

4.1 Organized Crime, Conspiracy, and Corruption in Procurement

The organized crime studies in law and social sciences are long familiar with the organization's analytical model of a network [34] and, more recently, with network analysis applied to criminal cases [24, 35]. According to Steffensmeier, the normative concept of organized crime groups is typically defined after three main characteristics: a formalized structure whose primary objective is to obtain money through illegal activities, the structure's activity has continuity over time, and it maintains its position through use

of violence or threat of violence, corruption of public officials, and extortion [34]. Networks as criminal organizations are difficult to prosecute because they camouflage information and actions, and they grant impunity by adding security actors, such as public functionaries and politicians [34, 36], and also by acting in criminal conspiracy.

Conspiracy is a legal crime convenient when there is no substantive proof that an offense has been committed and evidence has been covered, but the agreement for fraud exists, and the centrality of the group activity is apparent as a "single invisible empire" [37]. Therefore, as a complexity problem, the recognition of factors that trigger criminal conspiracy for corruption in public procurement represents a step forward in predicting certain behaviors and discussing control strategies. In this research, criminal conspiracy is considered as an organized crime act or as "an agreement between two or more people to commit an illegal act, along with an intent to achieve the agreement's goal." The analysis of the procurement environment as a network commonly considers the connections between the contracting institutions and suppliers, either under a bipartite institution–supplier network or a firm–firm co-bidding network [8, 17, 20]. However, the information regarding the connections of public servants and business people to their corresponding institutions or companies, respectively (beyond hidden political ties), is an aspect that can be further explored. In particular, our results tell of the importance of the analysis of the supplier environment of a given country under a network and complex system approach, and of the relevance of creating network-based corruption indicators at the level of ownership and management of the companies involved in procurement.

The risk in procurement networks has also been qualified by a centrality proxy that opposes competition legislation [17]. The present research argues that while centrality is relevant as a normative risk indicator, it might not be useful in a political context where the rule of law is deteriorating and large-scale public and private actors acting unlawfully is common (see Data and Methods regarding the Mexican scenario).

4.1.1 Complexity Science Approaches to Conspiracy Networks

Corruption is a phenomenon that occurs within the structure and dynamics of complex social, economic, political, and technological systems. Although there is no general consensus on a comprehensive definition for complex system, in this study, we considered the following: complex systems are networks made of a number of components that interact with each other, typically in a nonlinear fashion. Complex systems may arise and evolve through self-organization such that they are neither completely regular nor completely random, permitting the development of emergent behavior at macroscopic scales [38].

As such, corruption in public procurement manifests as a non-separable or intertwined activity that takes places within a complex procurement system defined by contracting institutions, suppliers, public servants, and business people interacting through tendering processes, awarded contracts, labor relationships, and through hidden ties or connections [8, 12, 15]. At the level of ownership and management of the companies involved in procurement, this

definition allowed us to hypothesize the criminal conspiracy (as a proxy for corruption) of corporations as an underlying behavior that creates connections among companies with shared personnel and that could be identified and quantified through the macroscopic properties of the corporate networks. First, we found that the companies involved in the scandals have unusual corporate profiles full of multi-role personnel, especially Case 1 (**Figure 1**). Also, the rate of creation of companies compared to the rate of addition of new personnel displayed some common patterns, except for Case 1 (**Figure 2**). Then, the analysis was performed under an empirical bipartite company–personnel network approach that allowed us to do the following: i) show how companies indeed nucleate into networks, with different properties, due to the existence of shared multi-role personnel, pointing toward potential criminal conspiracy activity (**Figure 3**); ii) describe and quantify the subtle differences and similarities in the structure and dynamics of the corporate networks for each corruption scandal (**Figure 4**); iii) show the degree to which the companies behave in a conspiracy fashion by introducing a conspiracy indicator, ϕ_C, based on the fraction of connected components of each network (**Eq. 5**); and iv) identify some elements that contribute to the description of corporate criminal conspiracy based on network-based metrics, specifically, the conspiracy-clustering description (**Figure 5**). The conspiracy-clustering description (see **Figure 5F**) generated a relevant classification of the cases that are in an interesting correspondence with their general features, such as scale of operation and percentage of shell companies involved: Veracruz, Case 1 (local scale of operation with less than 50% of shell companies involved) evolves in time toward the low clustering and high conspiracy region I; Puebla y Guanajuato, Cases 2 and 3 (local scale of operation with close to 100% of shell companies involved) remain within the low clustering and low conspiracy region III; and Federation, Case 4 (federal scale of operation with less than 50% of shell companies involved) falls into the high clustering and low conspiracy region IV.

We would like to remark that although our analysis is able to differentiate the corrupt cases in terms of the conspiracy and other metrics (such as the clustering) of the corporate networks, it still needs to be applied in a context that also includes non-corrupt companies in order to test its capabilities to classify corrupt from non-corrupt patterns. Also, one downside of our analysis is that so far, we have no evidence to conclude that these network structures are features of the whole ecosystem. As such, our research does not replace or substitute traditional corruption approaches or research on the procurement environment, but brings more elements to consider regarding corporate risk indicators based on the network properties of companies connected at the ownership and management level before any tendering process or contract is awarded.

4.1.2 Professional Practice and Further Research

Corruption practices in procurement processes have been extensively explored in the literature [8, 39], and it has been relevant to promote standards, legislation, and enforcement mechanisms in order to prevent opportunities for behaviors such as collusion, bid-rigging, and cartel agreements [17, 20,

40, 41], often by looking at the economic incentives and punishment rules [42, 43]. Global strategies seek to increase transparency, convenience, higher revenue in procurement through electronic government procurement [2, 4, 44, 45], and improve the value of reputation of the suppliers with compliance policies [46–48]. The underlying presumption seems to be that governments' purchasing decisions are influenced by legitimate concerns and governments are willing to work with firms with a reputation, where public–private partnership will be endorsed within the compliance of domestic and international legal framework and codes of ethics [9]. Nevertheless, the assessments and risk metrics in procurement are becoming more comprehensive in order to fully ascertain the presence of organized crime acting in conspiracy and other offenses such as collusion and fraud in a way that they promote competition on the bases of law enforcement scenarios [49, 50]. Governments are the controllers and the responsible parties for enforcing anti-corruption legislation, but fragmentation, electoral interests, or private gain often diverts public officials from public purpose, and corruption is more difficult to detect [51].

The cases presented in this study represent examples of corruption where the government officials such as governors; heads of federal and state agencies, companies, and notaries; and natural persons undertake corruption action plans allegedly for electoral and self-profit ends. In contexts where governments are acting unlawfully, buyers and/or suppliers are acting in conspiracy with the obvious intent to remain undetected, and public officials protect or act in collusion with corporate networks; information traces hidden in journalistic investigations remain one of the best tools to expose criminal activities. Using corruption scandals data precisely benefits scientific analysis by often proving that regardless of a comprehensive legal framework, procurement practices overtake normative rationality, to serve a practical realpolitik system that poses a challenge to the design of corruption proxies and network analysis. Also, by analyzing corporate corruption under a network's perspective, it is possible to avoid biases, such as taking for granted honesty, firm's reputation [18], or public officials' lawfulness, that go beyond the risks posed by single author's offenses into patterns of racketeering activity [37].

Further research should delve into which corporate characteristics are likely to maximize connectivity by exploring the contribution of each personnel layer to the macro properties of the network together with the heuristic function for alleged conspiracy introduced in this article. Also, with more official information about the cases regarding government participation and financial transactions or taxpayers activities, extra analysis could assess the role of government in perpetuating and protecting corruption networks in procurement.

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Likewise, the more corruption judicial cases there could be before courts, the better understanding of the wrongfulness of the conspiracy activities could be categorized.

DATA AVAILABILITY STATEMENT

AUTHOR CONTRIBUTIONS

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