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INFERENTIAL ANALYSIS OF ROAD INFRASTRUCTURE PPP SPONSOR NETWORKS

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ABSTRACT

In the road infrastructure sector, public-private partnership (PPP) projects involve the implementation of project finance principles through the signing of a long-term contract between the public authority and a group of sponsors assembled in a Special Purpose Vehicle (SPV). However, although PPP sponsors play a very important role in SPV formation, the literature does not provide ample evidence to understand such creation processes. Therefore, this study gains insight into the mechanisms associated with the way PPP sponsors establish relationships among themselves in order to form SPVs. The approach employs social network concepts and Exponential Random Graph Model (ERGM) techniques. The analysis is focused on tie-formation processes in sponsor networks across the bidding and financial close stages of road PPP projects in Canada, Chile, and the US between 1993 and 2019. Results show that, despite some differences in the studied jurisdictions, dyadic (i.e., repeated relationships) and structural (i.e., transitivity) factors are the most influential properties driving bidding consortium and SPV creation procedures. Conclusions indicate that sponsors' behavioral patterns are highly influenced by trust-based mechanisms. Further research is required to continue understanding the role of other PPP players and the effect of the external institutional environment on PPP networks.

KEY WORDS: Social network analysis, public-private partnerships, exponential random graph models, equity providers.

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INTRODUCTION

Public-private partnerships (PPPs) have been employed to deliver road infrastructure assets in jurisdictions that lack immediate budget availability and wish to expand and improve their road network without privatizing or renouncing control (Jin et al. 2020; Sugawara and Nikaido 2014; Swanson and Sakhrani 2020). In a PPP project, the public sector transfers specific risks and responsibilities to private partners in exchange for proper economic returns (Chung 2016; Demirag et al. 2012). To do so, the transaction requires a long-term agreement between public and private parties. While the former is represented by the contracting authority, the latter comprises a group of investors associated in a separate legal entity, called a special purpose vehicle (SPV) (Esty 2004; Garvin and Bosso 2008).

An SPV brings together the private parties involved in the project and constitutes the contracting authority's counterpart in a PPP agreement (Sugawara and Nikaido 2014). Although SPVs are responsible for managing and executing the activities specified by public procurers in PPP contracts, the main reasons for their utilization are related to financial considerations (Esty 2004). For every PPP initiative, the creation of an SPV allows private partners to isolate the initiative in a separate organization in order to secure non-recourse debt resources, prevent the project's assets and liabilities from appearing in the investors' financial statements, and protect the project from corporate bankruptcies (Burke and Demirag 2019; Grimsey and Lewis 2004).

Although SPVs may involve firms with multiple interests and backgrounds, the sponsors are the SPV members that play the most important role during the bidding and financial close stages (Grimsey and Lewis 2004; Hussain and Siemiatycki 2018). Sponsors refer to the group of investors (i.e., usually two or three firms per project) responsible for creating the bidding consortium and submitting the project tender (Sugawara and Nikaido 2014). If selected as preferred proponents, they are in charge of creating the SPV and the shareholding agreement, as well as committing equity and achieving financial close (Burke and Demirag 2019; Koc and Gurgun 2021; Siemiatycki 2011).

Given the aforementioned responsibilities for PPP sponsors and considering the long-term uncertainties and contract and institutional complexities (Casady 2020; Casady et al. 2020; Castelblanco et al. 2021b) of public-private agreements (Cruz and Marques 2013; Guevara et al. 2020b); the formation of relationships associated with bidding consortiums and SPVs plays a key role in PPP development. Building on social network methodologies (Borgatti et al. 2009; Moreno 1937), PPP scholars have recently applied inferential statistical methods to network-based studies in order to gain insight into PPP markets' characteristics and SPV's tie-formation mechanisms (e.g., Sedita and Apa 2015). However, despite their advantages, traditional inferential methods, such as statistical regressions, can only analyze networks by assuming that observations are statistically independent (Snijders and Borgatti 1999). This supposition is problematic because it does not consider the influence of interrelational effects on the way PPP sponsors establish mutual relationships.

Considering the difficulties associated with inferential statistics in the social network field, in recent years, Exponential Random Graph Models (ERGMs) have been used to verify hypotheses that capture dependency (i.e., network relationships) among observations (i.e., PPP sponsors) (Pattison and Robins 2002; Robins et al. 2007). Based on ERGM postulates, tie-formation mechanisms between investors can be examined through perspectives associated with node properties (e.g., nationality or expertise) (Gu and Lu 2014; Rose Kim et al. 2016), network features (e.g., the tendency of investors to form triads based on common mutual connections) (Diestre and Rajagopalan 2012; McPherson et al. 2001), and dyad-based attributes (e.g., recurrent relationships) (Lusher et al. 2013; Podolny 1993; Podolny and Stuart 1995). Accordingly, this paper seeks to characterize and explain the relational mechanisms governing SPV formation processes in road PPP projects via social network concepts and ERGM models generated by collecting data on sponsors' participation during tendering and financial closure processes. To do so, PPP sponsor networks in three PPP markets across the Americas (i.e., Canada, Chile, and the United States) are studied from 1993 to 2019.

THEORETICAL BACKGROUND

This section presents the theoretical information required to understand the social network and ERGM concepts proposed in this study. First, a description of the characteristics associated with PPP sponsors is presented. Subsequently, a basic definition of network formation processes at the node-, dyad-, and network-based levels is proposed. Finally, the main formulations, parameters, and statistics related to ERGMs are identified.

Sponsors in the PPP Procurement Stage

For every PPP project, linkages among sponsors are created throughout the tendering process and consolidated during the financial close stage as the SPV is formed (Grimsey and Lewis 2004; Sugawara and Nikaido 2014). Because SPV members may change during the construction and operation phases, the original sponsors play a crucial role in the procurement stage of any PPP project (Burke and Demirag 2019; Feng et al. 2017; Kwak et al. 2009). They are the principal shareholders and are in charge of committing equity (i.e., typically between 5% and 30% of the contract value) and securing a proper risk management structure for lenders to be able to provide non-recourse debt (Grimsey and Lewis 2004; Sugawara and Nikaido 2014). Based on that, sponsors are at higher financial risk, as the rate of return on the equity is higher than on the debt (Carrillo de Albornoz et al. 2018; Owolabi et al. 2020).

Scholars have described PPP sponsors according to the nature of their activities as financial organizations, non-financial investors, and a combination of these two (Grimsey and Lewis 2004; Sugawara and Nikaido 2014). Financial investors include firms such as banks, insurance companies, and pension or infrastructure funds. These organizations typically do not seek to be involved in activities outside the financial field (Lu et al. 2019). The non-financial group includes companies focused on providing equity as a way to secure subcontracts across the construction and operational stages. These refer to the construction and engineering contractors, operation and maintenance firms (Chowdhury et al. 2011; Chung et al. 2009), and other technical consultants (Rossi and Stepic 2015). Finally, the third group of firms comprises those interested in both financial and non-financial aspects. These are referred to in this paper as infrastructure developers with core expertise in design and construction activities but capable of committing equity, secure debt resources, and manage all PPP lifecycle phases (Burke and Demirag 2019; Siemiatycki 2011, 2013).

Based on the above, the creation of bidding consortiums and SPVs is influenced by how sponsors seek to mitigate PPP risks through establishing relationships based on both contractual ties and trust-based linkages (Burke and Demirag 2019; Guevara et al. 2020b; Hetemi et al. 2020). In this sense, weak SPVs may generate project difficulties that manifest themselves in poor project administration, delivery time delays, and cost overruns (Osei-Kyei and Chan 2015; Owolabi et al. 2020). For such reasons, sponsors must seek partners with whom project-related risks may be mitigated (Carrillo de Albornoz et al. 2018; Grimsey and Lewis 2004) and with whom they can improve their effectiveness and achieve competitive advantages (Delhi and Mahalingam 2020; Edkins and Smyth 2006; Wang and Zhang 2019). In line with that, a key challenge for sponsors interested in PPP projects is finding bidding partners with sufficient funds, reputation, and the capacity to compete in PPP markets (Burke and Demirag 2019; Guevara et al. 2020b; Osei-Kyei et al. 2018). Consequently, the formation of associations with strong technical, administrative, and operational abilities is vital (Burke and Demirag 2019; Siemiatycki 2013).

Network Formation Processes

To gain insight into the way PPP sponsors establish relationships across the bidding and financial close stages, it is necessary to examine the extant literature on network formation processes. Researchers refer to such processes as mechanisms capable of explaining the creation of relationships between actors and the emergence of network structures (Lyubchich and Woodland 2019; Mele 2017). These processes are driven by social properties at the actor, dyad, and network levels (Cranmer et al. 2012; Rose Kim et al. 2016; Scott 2016). At the actor level, studies suggest that firm-specific characteristics play a key role in the shaping of relationships between two or more organizations. This is because firms may exhibit different propensity degrees to establish linkages with other network partners by considering their own background or organizational skills. These may include, for instance, features related to nationality, expertise-related capabilities, and organizational reputation, among others (Cheung et al. 2012; Park and Kim 2020; Suwal and Cui 2019).

At the dyad level, researchers report that firms may seek to establish inter-organizational ties with partners exhibiting either similar or different attributes (i.e., homophily) (Rose Kim et al. 2016; Wasserman and Pattison 1996). In this way, from this perspective, relationship formation processes are driven by the firms' efforts towards establishing linkages with organizations capable of offering analogous or complementary skills. In this context, prior relationships between two actors have a clear influence on tie formation processes because the presence of repeated relationships strongly indicates high levels of trust and shared values (Goerzen 2007; González and Verhoest 2018).

Apart from the actor- and dyad-related characteristics, scholars have employed network-specific properties to gain insight into how the presence of different patterns of relationships across networks influences the way actors to interact with each other (Lusher et al. 2013; Robins et al. 2007). Some studies have shown that network participants may have a tendency to form ties with central actors (i.e., prominent and well-connected organizations) because highly visible and influential firms may provide enhanced capabilities and resources to their partners. This follows processes known as "star" arrangements because the emergent structures contain multiple connections associated with a specific dominant actor (Podolny 1993; Podolny and Stuart 1995); resulting in a phenomenon in which "the rich get richer" (Barabási and Albert 1999; Merton 1968). Additionally, researchers have also explored the tendency of actors to form transitivity triads, as any two unconnected network participants are likely to establish a mutual relationship if they are each connected with a separate third common partner (Lazega et al. 1995). In this way, triangles of interactions are created by following the idea of "a friend of my friend is my friend". Consequently, network-specific properties are not only complementary to actor- and dyad-level characteristics but also very important at the moment of quantifying the effect of network structures on actors' relationships (Rose Kim et al. 2016).

ERGMs in Network Formation Processes

Researchers have employed ERGMs to examine tie-formation processes at the node-, dyad-, and network-level. These models have emerged as inferential statistical tools through which graph theory can be applied in order to examine interdependencies between individual observations and network behaviors (Robins et al. 2007; Snijders and Borgatti 1999). In contrast to traditional regression models (e.g., logistical regressions), ERGMs can use relational data to analyze how relationships between any two actors may be explained by reasons associated with network characteristics beyond individual node attributes (González and Verhoest 2018). This allows ERGM scholars to study endogenous (i.e., network-specific properties) and exogenous (i.e., actor- and dyad- configurations) network features by considering interdependent relationships (Pattison and Robins 2002; Wasserman and Pattison 1996).

For any observed network, an ERGM assumes that such structure is formed by random processes that can be characterized through an exponential family of probability distributions (Amati et al. 2018; Chakraborty et al. 2020). Mathematically, an ERGM considers a y network as a collection of N nodes that can be represented by a N x N adjacency matrix in which $y = [y_{i,j}]$ with $y_{i,j} = 1$ if there is a link connecting i and j. ERGM can be written in the following form (Chakraborty et al. 2020; Krivitsky and Butts 2015; Robins et al. 2007):

$$P\ (y, \Theta) = \frac{h(y)\exp(\sum_K \Theta_K S_K(y,x))}{K(\Theta)}, y \in Y \qquad (1)$$

Equation 1 defines the probability of observing any given network as a function of formulations, parameters, and statistics associated with the network nodes and linkages. The term (y) is a formulation that corresponds to a unique observation defined by all of the relationships that a given actor established within its network (i.e., the number of ties of the actor in the network) and (Y) is equivalent to all of the relationships groups that can be created (i.e., from a totally isolated network to a fully connected structure) (Kolaczyk 2009; Nordhausen 2015). The h(y) stands for a probability mass function that defines the weight of each tie, thus defining the number of times two actors have repeatedly participated together (Rose Kim et al. 2016).

The term Θ_k indicates a vector of unknown parameters used to determine how the observed network can be described through the network statistics included in the model (Amati et al. 2018). Such measures are denoted by the $S_k(y,x)$ function, which incorporates a vector of the network configurations employed for the study and hypothesized to influence tie-formation processes (Amati et al. 2018; Nordhausen 2015). These statistics may comprise node- (e.g., expertise and nationality of actors), dyad- (e.g., repeated relationships), and network-based attributes (e.g., number of star-based structures and transitivity triads). The k refers to the multiple network configuration typologies utilized for the model. The denominator $K(\Theta)$ acts as a normalizing constant to include space for all possible realizations (Y) and constraints the probabilities to sum to 1 (Chakraborty et al. 2020; Rose Kim et al. 2016).

Based on the above, ERGM scholars select the network they want to study (i.e., the observed structure), specify h(y) as per the number of repeated relationships, and estimate Θ_k parameters in line with pre-defined specific $S_k(y,x)$ statistics. However, because of the normalizing constant, it is necessary to determine Θ parameters for all possible network configurations. This creates a computational problem because, for any undirected network with N nodes, there are $2^{\binom{N}{2}}$ possible arrangements (Geyer and Thompson 1992). Accordingly, researchers usually employ the Markov Chain Monte Carlo Maximum Likelihood (MCMCML) procedure as a method to calculate ERGM parameters (Cranmer et al. 2012; González and Verhoest 2018; Khalilzadeh 2018; Williams and Hristov 2018).

The MCMCML uses an iterative process focused on improving Θ by maximizing the logarithm of the maximum likelihood ratio (Geyer and Thompson 1992; Hunter and Handcock 2006). This can be done through the Markov algorithm proposed by Geyer and Thompson (1992). This algorithm generates Markov Monte Carlo chains for an initial parameter state Θ_0 and conducts an iterative optimization process focused on comparing simulated distributions of network arrangements with the observed data (Cranmer et al. 2012; Nordhausen 2015). The process continues until the objective formulation converges, ensuring that there is no change in the maximum likelihood function.

NETWORK PROPERTIES IN PPP SPONSOR MARKETS: RESEARCH HYPOTHESES

This section presents the research hypotheses under evaluation. Each hypothesis is formulated based on firm-, dyad-, or network-level attributes. This process is the first step to define the network statistics (i.e., $S_k(y,x)$ functions) required to develop the ERGMs proposed in subsequent sections.

Firm and Dyad level properties

The five different firm-and-dyad properties considered for this study are related to specific actors' characteristics (i.e., nationality, expertise, bidding record) and tie-related features (i.e., prior interlocks and closeness centrality).

The nationality of sponsors appears to be a varying attribute within PPP markets. The literature reports that bidding groups and SPVs in most PPP networks worldwide are formed by organizations with operations across three basic geographical levels: local (i.e., firms solely focused on specific regions within a country), domestic (i.e., investors with operations throughout their country of origin), and international (i.e., sponsors with investments in jurisdictions different from their country of origin) (Carpintero 2011; Guevara et al. 2020b; Roumboutsos et al. 2017; South et al. 2018). As suggested in the PPP body of knowledge, this geographical characterization is a proxy to understand if physical, organizational, and cultural similarities play a role in the formation of partnership linkages. So far, however, researchers have relied on qualitative assessments to examine such issues (Burke and Demirag 2019; Siemiatycki 2011, 2013). This means that there is limited empirical evidence about the importance of factors associated with geographical proximity in respect to tie-formation processes in PPP sponsor networks. For instance, the literature does not provide enough clarity in terms of understanding how local firms developing PPP projects in specific regions within a country may tend to connect with domestic or foreign investors in order to incorporate external ideas and expertise into their organizational processes. As a result, this study has established Hypotheses 1.1, 1.2, and 1.3 as follows.

Hypothesis 1.1: From 1993 to 2019 and for the studied PPP markets, domestic sponsors tended to establish collaborative ties with international sponsors.

Hypothesis 1.2: From 1993 to 2019 and for the studied PPP markets , domestic sponsors tended to establish collaborative ties with local sponsors.

Hypothesis 1.3: From 1993 to 2019 and for the studied PPP markets, local sponsors tended to establish collaborative ties with international sponsors.

Similar to geographic-related attributes, the extant PPP literature reports that it is important to examine PPP sponsors by considering the nature of their activities (i.e., *expertise)* (Roumboutsos et al. 2017; Siemiatycki 2013). Based on that, sponsors are usually classified into the three categories (i.e., financial, non-financial, and infrastructure developers) defined in a previous section (Yescombe and Farquharson 2018). This classification has allowed scholars to gain insight into the role played by each group in the light of PPP bidding and financial close procedures (Burke and Demirag 2019;

South et al. 2018). However, the literature mostly provides segmented qualitative analyses in which it is not clear up to what point the aforementioned typologies are integrated. For instance, some scholars recognize that financial sponsors are important to PPPs and emphasize that such organizations can be willing to directly fund the development of infrastructure projects worldwide; however, these players do not usually make such investments because of the governance challenges associated with PPP projects (Guevara et al. 2020a; Levitt and Eriksson 2016). On the other hand, some other authors highlight that the construction companies are better positioned for leading PPP projects in the transportation sector (Roumboutsos et al. 2017). As a result, despite some prominent examples (i.e., Ontario Teachers' Pension Fund) it remains unclear the complete extent of the collaboration between sponsors with different expertise backgrounds (Levitt and Eriksson 2016)

In general, researchers have not provided sufficient empirical evidence regarding how sponsors with different expertise and from dissimilar backgrounds organize themselves to bid for projects. This is important because studies suggest that construction and operational risks are some of the most important risks borne by PPP sponsors. Accordingly, one can expect financial investors to seek connections with organizations capable of undertaking construction and operation actions (i.e., non-financial firms or infrastructure developers). Consequently, for the purposes of this study, Hypothesis 2 is presented below.

Hypotheses 2: From 1993 to 2019 and for the studied PPP markets, sponsors categorized as financial investors (i.e., firms without expertise in construction/operational) tend to join forces with sponsors with experience in construction, operation, or maintenance areas (i.e., non-financial investors and infrastructure developers).

Besides the nationality and expertise, being a successful bidder is another important actor-level characteristic within PPP markets. It is logical to think that sponsors with low winning records may have a tendency to establish relationships with investors characterized by having being selected as preferred proponents in multiple projects (Castelblanco et al. 2021a; Li et al. 2020; Ye et al. 2018).

However, successful bidders may be inclined to avoid forming ties with actors exhibiting a losing record. Consequently, one can expect PPP networks to show successful sponsors forming clusters of relationships among themselves. This leads to Hypothesis 3, as shown below.

Hypothesis 3: From 1993 to 2019 and for the studied PPP markets, sponsors with winning records tend to connect with other firms that have also been successful in their bidding processes.

Apart from the firm-specific characteristics, dyad-level properties may also play a crucial role in PPP networks. This effect can be captured by examining prior interconnections and analyzing social network measures. In respect to prior interactions, studying the way sponsors repeatedly establish linkages with the same partners is a means to evaluate if such relationships constitute long-term alliances based on mutual trust and shared values. In this context, long-term relationships may improve the value of collaborative ties, thus enhancing the exploitation of common knowledge and increasing the chances of PPP projects to achieve successful outcomes (Aloini et al. 2015; Burke and Demirag 2019; Manu et al. 2015; Siemiatycki 2011; Solheim-Kile and Wald 2019). Consequently, in order to test the tendency of PPP networks to be formed through a series of recurrent interactions between sponsors, Hypothesis 4 is proposed.

Hypothesis 4: From 1993 to 2019 and for the studied PPP markets, sponsors tended to replicate relationships at the moment of bidding for new projects.

The concept of centrality is another dyad-based factor useful to understand PPP sponsor's behaviors within PPP markets (South et al. 2018; Zheng et al. 2016). This is because actors with high levels of centrality have the potential to control communications and influence collaborative networks (Chinowsky et al. 2008; Freeman et al. 1979; Moreno 1937). Although there are multiple centrality-based indicators focused on capturing different properties within a network (Freeman 1978; Freeman et al. 1979), Closeness Centrality (CC) is seemingly the most appropriate to analyze the ways sponsors are mutually connected within the network (Pryke 2004; Wasserman and

Galaskiewicz 1994). This measure of proximity between sponsors may give an indication of the ability of firms to get access to information through other investors (i.e., firms with high CC levels). With this information, Hypothesis 5 is proposed as follows.

Hypothesis 5: From 1993 to 2019 and for the studied PPP markets, sponsors with high CC values have higher probabilities of establishing relationships among themselves than with other firms.

Network level properties

Network attributes are important drivers of tie-formation processes because of generating structural effects (i.e., a combination of linkages between nodes) that have an impact on how actors make relationships (Park et al. 2018; Rose Kim et al. 2016). Transitivity is one example of such network properties and refers to the tendency of two unconnected sponsors to form a tie if they are independently connected to a third common partner (Chakraborty et al. 2020; Prell 2011). This is important because most SPVs are formed by more than two players (Guevara et al. 2020b; Sugawara and Nikaido 2014). In other words, it is reasonable to assume groups of three sponsors to bid for a PPP project. Consequently, this study assumes that a transitivity effect is expected in all collaborative networks and can be studied through Hypothesis 6.

Hypothesis 6: From 1993 to 2019, sponsors tended to form triangle-like structures in the studied road PPP markets.

Finally, it is necessary to examine formation processes via network-based indicators (Borgatti et al. 2009; Freeman 1978; Pryke 2004; Wasserman and Galaskiewicz 1994). In order to do so in a collective way, the concept of 2-star networks can be employed as this incorporates the effects of other k-star configurations (González and Verhoest 2018). This refers to a specific typology of network structures in which participants tend to prioritize links with prominent and well-connected players, thus forming star-like configurations around central nodes (Gondal 2011; Rose Kim et al.

2016). Because the presence of these structures is not uncommon in project-based networks, it is reasonable to characterize PPP sponsor markets as networks dominated by organizations exhibiting high-centrality values in which most firms favor linkages with such dominant players. Hypothesis 7 is proposed accordingly.

Hypothesis 7: From 1993 to 2019, sponsors tended to form by 2-star structures in the studied road PPP markets.

RESEARCH METHODOLOGY

This study seeks to analyze tie-formation processes in sponsor networks within the road PPP markets of Canada, Chile, and the US. In particular, this study focuses on the tendering (i.e., pre-qualified participants) and financial close (i.e., preferred proponents) stages of specific road PPP projects developed in such countries between 1993 and 2019. The three aforementioned three countries were chosen because of their similarities in respect to the application of project finance principles for PPP initiatives, even though these three markets have different levels of maturity and institutional characteristics (Casady et al. 2018, 2019). In this regard, central and regional governments within these jurisdictions provided information that allowed the authors to verify that all selected projects were initiatives characterized by using sponsors' equity at risk, non-recourse debt, and multi-stage tender processes (Esty et al. 2014; Grimsey and Lewis 2004; Yescombe and Farquharson 2018). This helped to ensure that all relationships within the proposed networks represented a very similar set of practices regardless of project locations and institutional features. In other words, despite the differences in PPP development processes across national and sub-national regions, the three selected markets offered analogous initiatives from a sponsor's perspective, as all studied PPP projects followed project finance principles. Furthermore, these markets share characteristics such as the number of PPP sponsors, average relationships per investor, average SPV size, and the number of road infrastructure projects with financial close in a similar time interval (Guevara et al. 2020b). Accordingly, following the definitions provided by Yescombe and Farquharson (Yescombe and Farquharson 2018), this study is based on projects categorized as Design-Build-Finance-Operate, Design-Build-Finance-Maintenance-Operate, Build-Transfer-Operate, and Build-Operate-Transfer.

In general, the road PPP networks in this investigation are bounded to the information-exchange relationships established by sponsors across the bidding and financial close stages of PPP projects within three specific countries. Consequently, this work sought to gain insight into the underlying mechanisms associated with the way PPP sponsors establish connections among themselves. The methodology followed four sequential methodological stages discussed subsequently.

Stage 1: Data Collection

Following the process described in Guevara et al. (2020), the authors gathered information from three PPP databases: Inframation Deals, Public Work Financing, and InfraPPP World (Inframation Deals 2019; InfraPPP World 2020; Public Works Financing (PWF) 2019). These databases were selected because they are among the most reliable and accessible sources of information available online. The authors searched for information regarding the participation of sponsors in PPP tendering processes before and after contract award. Additionally, for each sponsor, data about the role (expertise of the company), nationality, and the number of projects procured were collected. Complementary information was gathered from company and project websites, news articles, and online reports. Further data were collected from official websites on which these countries publish their PPP procurement processes: Mercado Público and the Ministerio de Obras Públicas in Chile (Ministerio Obras Publicas 2021), the Canadian Council For Public-Private Partnerships, and its P3spectrum database (The Canadian Council for Public-Private Partnerships 2021), and the Federal Highway Administration Center for Innovative Finance in the USA(The Federal Highway Administration (FHWA) 2021). Based on Guevara et al. (Guevara et al. 2020b), Table 1 shows the studied projects, and Table 2 depicts the prequalified investors and sponsors selected as preferred proponents in such initiatives.

Table 1. PPP projects under study

Table 2 Main road PPP Sponsors

Stage 2: Model Inputs

For each PPP transaction in all three countries, the collected information was organized according to the identity and relationships of every sponsor across the bidding and financial close phases. The extracted data were classified into two main datasets per jurisdiction: prequalifying bidders and preferred proponents. Based on these lists, a total of six two-mode reference matrices W_{ij} were developed. In each one of them, rows indicated sponsor names, and columns denoted PPP project titles. For each cell in $W_{ij,}$ a value of 1 was allocated if investor i participated in project j, vice versa a value of 0 was assigned (Guevara et al. 2020b). In every column, for each Wij=1, bidding consortiums and SPVs were identified with colors so that, all the cells with the same color represented participants belonging to the same group of investors, as color similarities/differences within the same project helped to identify consortium partners from competitors. This process independently repeated itself in each column, helping the authors to define partners and competitors by considering that two sponsors may collaborate in one specific PPP (i.e., same color code), while being competitors in another initiative (i.e. different color code). In this way, prequalified bidders were organized in 56x30, 58x32, and 56x32 matrices for Canada, Chile, and the US; preferred proponents were arranged in 32x30, 28x32, and 31x32 matrices, respectively. Subsequently, each one of the six matrices W_{ij} was multiplied by their transpose in order to obtain six adjacency matrices A_{ij}. For every A_{ij}, rows and columns denoted investor names, and cell values different from 0 indicated the number of times $Sponsor_i$ and $SponSor_j$ had formed part of the same consortium.

Consequently, each adjacency matrix embodied a relational network and represented the function *y*, as defined in Equation 1.

Apart from the adjacency matrices, the authors quantified the number of repeated relationships per tie and defined the network statistics to be employed in the ERGMs. The data about recurrent relationships were used to build the probability mass function h(y) as specified by Equation 1. On the other hand, considering that ERGM statistics are associated with multiple network configurations and embodied by the $S_k(y,x)$ functions in Equation 1, the authors defined five different configuration typologies to represent the seven hypotheses depicted in the previous section.

As shown in Table 3, $S_1(y,x)$ represented the baseline for calculating probabilities of tie-formation without taking into account external attributes. $S_2(y,x)$ allowed for examining the tendency of actors for establishing relationships with at least two different partners (i.e., 2-stars relationships [H7]). $S_3(y,x)$ focused on measuring the propensity of sponsors to form triads (i.e., relationship triangles [H6]) (Lusher et al. 2013). $S_4(y,x)$ contributed to model discrete categorical properties, allowing researchers to explore relationships between two sponsors by considering combinations of firm-based features (i.e., the tendency of two investors to establish a relationship in case of sharing a common/different property such as nationality [H1] and expertise [H2]). Finally, $S_5(y,x)$ measured properties at the firm-level by considering numerical categorical and continuous attributes (i.e., the tendency of two sponsors to form a tie by considering the number of previous recurrent connections [H3], the number of successful bids [H4], or their CC values [H5]).

Stage 3: ERGM Estimation Processes

In this study, ERGMs were employed as statistical tools to uncover how inter-organizational linkages were formed between PPP sponsors. Such models were estimated independently for sponsors categorized as prequalified bidders (PQB) and preferred proponents (PP) in each studied country. Thus, six separate estimation processes were conducted (i.e., two per country), and the dependent variable in each one of them was the formation of ties between the sampled investors participating on either the PQB or the PP networks.

Following Equation 1, each of the six model estimation processes sought to determine the vector of unknown parameters Θ_k associated with a specific observed network by considering the aforementioned model inputs. This was done by conducting a nested methodology in which two statistical models were evaluated per estimation procedure. The first of these contained a baseline (e.g., tie) and firm- and dyad-level statistics (e.g., nationality, expertise, successes, closeness centrality, and repeated relationships). The second, in addition to incorporating such properties, contained network-level measures (e.g., triads and 2-star structures). This helped to examine the effect of structural mechanisms on tie formation processes.

Overall, the authors followed MCMCML procedures and employed the Statnet package within the R programming language (Handcock et al. 2019; Hunter et al. 2008). This allowed the authors to determine model parameters and obtain information about the significance of each hypothesized network configuration in respect to the observed relational arrangements. The specific Statnet terms employed to model the functions, statistics, and parameters associated with Equation 1 are described in Table 3.

Table 3. Network properties

Stage 4: ERGM Validation Processes

Several tests were performed to validate the proposed models' goodness-of-fit. In ERGMs, this can be examined through three main measures. The Akaike Information Criterion (AIC) refers to a statistical technique employed to estimate how likely a model is capable of estimating future values according to observed data (Akaike 1973; Forster and Sober 2011). The Bayesian Information Criterion (BIC) is an estimating method to evaluate predictive accuracy and models' average likelihood (Forster and Sober 2011; Schwarz 1978). The Spectral Goodness-Of-Fit (SGOF) is a statistic used to compare how well a network model explains the network structure of the observed data (Shore and Lubin 2015). For the first two measures, when comparing two nested models, the lower the values of AIC and BIC denote, the better the fit between simulated and observed data. In respect to the third metric, an SGOF with a value of one means that the model is an exact representation of the observed data. In line with that, and considering that SGOF may be negative, any value between zero and one indicates that model parameters are capable of explaining observed network attributes. Overall, validation procedures were conducted in the spectralGOF package within the R programming language (Shore and Lubin 2015).

RESULTS

The results of the ERGMs are presented in Tables 4 and 5 for the PP and PQB networks, respectively. In both tables, while Model 1 includes firm- and dyad level properties (five measures in total), Model 2 additionally incorporates network-level features (seven metrics in total). Each one of these statistics is associated with the seven hypotheses described in previous sections. In this sense, Model 1 serves as a benchmark to compare the effects of the network-based attributes contained in Model 2.

Table 4 ERGM results – Preferred Proponent Networks

Table 5 ERGM results – Prequalified Bidder Networks

The tie parameter indicates the baseline tendency of sponsors to establish relationships and is equivalent to the intercept term in log-linear models or grand mean in ANOVA. Its negative and significant value in all models and networks suggests that the studied structures are sparse and that interlocks rarely occur (Amati et al. 2018; Rose Kim et al. 2016).

In respect to Hypotheses 1.1,1.2,1.3, Table 4 shows that Models 1 and 2 do not support *Nationality-related* statistics in any of the three jurisdictions. Overall, this indicates that geographical differences associated with the origin of PPP sponsors are not likely to play a role in tie-formation processes in PP networks. On the other hand, for PQB networks, results are only marginally significant in Canada for Hypothesis 1.1, as depicted in Table 5. This suggests that there is a slight tendency of domestic Canadian bidders to engage with international organizations. However, based on Table 4, such interconnections are not likely to be important for preferred proponents.

Results for Hypotheses 2 suggest that this proposition is not supported within any PP network and it is only marginally supported by Model 2 in the Chilean PQB network. This indicates that *Expertise* properties are not significant to explain the nature of relationships between preferred proponents. Additionally, they only seem to be influential in the Chilean market when network-level attributes are incorporated into the analysis. Consequently, the differences in investors' *expertise* are not a highly influential factor at the moment of establishing SPVs.

Regarding Hypothesis 3, results indicate support within the two US-based networks. For the Chilean market, this assumption is only marginally supported when structural properties are considered in both PP and PQB networks. Additionally, for Canada, *Successes* only seems an important feature in tie-formation processes when network-based properties are examined in PP networks. Consequently, although not irrelevant for explaining interlocks among sponsors in the three studied countries, the most influential role played by *Successes* takes place in the American networks.

Tables 4 and 5 show that Hypothesis 4 is corroborated in all models and jurisdictions. This suggests that prior relationships among investors play a strong significant role in the formation of SPVs and bidding consortiums. On the other hand, Hypothesis 5 is also supported by all models in Table 5 (i.e., PQB networks). However, when considering PP models in Table 4, it is only supported in the Chilean and Canadian PP networks. Thus, establishing relationships with participants exhibiting high closeness centrality values is significantly important in five of the six studied networks.

In respect to Hypotheses 6 (i.e., *Transitivity)* and 7 (i.e., *2-stars),* model results show two different patterns. *Transitivity* is supported in all cases and exerts a positive and strongly significant effect in all networks. This suggests that sponsors are inclined to form triangle-like groups in order to bid for PPP projects and create SPVs. On the other hand, coefficients for *2-star structures* are negative and significant in Canada PP, USA PP, and Chile PP and PQB. This indicates that there is a tendency for sponsors not to form star-like arrangements around well-connected central players in such networks.

VALIDATION

To assess the way ERGMs fit to data, several statistical procedures were implemented. According to Tables 6 and 7, Model 2 exhibits lower AIC and BIC values than Model 1 in all countries and networks. Because Model 2 incorporates network-level features, this indicates that when structure-level parameters are considered, there is a better fit with the observed data. Therefore, Model 2 provides a better description of tie-formation processes between PPP investors. On the other hand, although SGOF results offer a better fit for PQB relationships than PP linkages SGOF, values higher than zero in this measure confirm that Model 2 provides an improved description of network linkages in all cases. As a result, the three statistics suggest that structural parameters had a high incidence in the modeling of all the studied networks.

Table 6. Validation Procedures for ERGM results - Preferred Proponents

Table 7. Validation Procedures for ERGM results - Prequalified Bidders

DISCUSSION

In general, the comparison of Models 1 and 2 suggests that tie-formation processes in PPP sponsor networks depend on a multiplicity of factors. Based on the proposed models, relationships between

PPP sponsors in the three studied markets emerge from the combination of characteristics associated with individual backgrounds (i.e., *Successes),* dyad connections (i.e., *Repeated Relationships* and *Closeness Centrality)*, and the networks as a whole (i.e., *Transitivity* and *2-starts)*. Although there are certain commonalities among the three countries across the two sets of networks, there are also important differences that emphasize the unique nature of each jurisdiction.

Results show that measures related to sponsors´ *Nationality* and *Expertise* are only capable of explaining tie-formation processes in the Canadian and Chilean PQB networks, respectively. Accordingly, the most influential firm-level characteristic is the one related to the reputation of investors (i.e., *Successes*), as the coefficients related to this statistic increase for Model 2 and are significant in all networks, except Canada PQB. This suggests that successful sponsors are likely to establish mutual relationships between them, as having a winning record in PPP transactions increases investors' trustworthiness in terms of their capabilities and resources for managing PPP projects. This confirms that, for most networks, successful bidders are in a better competitive position because of, among other factors, their capacity to establish better relationships (Roumboutsos et al. 2017; Siemiatycki 2013).

As for dyad-based measures, the *Repeated Relationships* variable is the only strongly-significant in all jurisdictions. The coefficients related to this statistic exert a positive effect that increases when network-level measures are considered in all models. This shows that PPP sponsors are more likely to establish connections with firms with whom they have previously worked together, as reported in other PPP-related studies (Burke and Demirag 2019; Siemiatycki 2011). It also empirically confirms that, given the risks involved in PPP projects, sponsors tend to consider trust-related characteristics at the moment of forming bidding consortiums and SPV groups. This is a behavioral pattern evidenced for long-term interorganizational alliances in other markets and industries (Goerzen 2007; Renato et al. 2020; Rose Kim et al. 2016).

In respect to *Closeness Centrality,* it is clear that such statistic plays a key role in interlock formation processes in all networks, except USA PP. Considering that this measure gives an indication of the importance of direct mutual communication processes and interactions among investors at the moment of bidding and forming SPVs for PPPs; it is empirically evident that relationships in the studied markets are affected by the sponsors' abilities to exchange information with other network participants (i.e., high *Closeness Centrality*). In this way, tie-formation processes are influenced by the capacity of investors to have access to more resources through connecting with dominant and central sponsors. This specific feature has also been found to be relevant in other project-based contexts (Poleacovschi et al. 2017; Sedita and Apa 2015).

In terms of network-based effects, the significantly positive *Transitivity* effect in all networks suggests that in such arrangements, there are closure mechanisms (i.e., the tendency of network actors to form triangles). These may give rise to denser sub-regions within networks in which unconnected sponsors having linkages with a third common partner have a tendency to mutually engage in PPP transactions. As a result, two unconnected sponsors are more likely to form a bidding group or SPV if they know a third common partner. This result is consistent with prior literature reporting that synergistic interlocks between SPV partners are positive for PPP development (Burke and Demirag 2019; Guevara et al. 2020b; Siemiatycki 2013).

On the other hand, the negative and significant *2-star* effect reveals a propensity against centralization in all PP networks and in the Chilean PQB structure. Although such effect is low, it is a clear indication that PPP sponsors are not likely to follow preferential attachment mechanisms in tie-formation processes. This means that relationships are not created as a result of a "the rich get richer" tendency in which prominent, well-connected firms (i.e., high centralization) dominate PPP transactions (Amati et al. 2018; Cao et al. 2017). Consequently, sponsors do not tend to form SPV linkages with central players by relying on the number of connections of such actors. They are inclined to do so through considering other firm-based properties (i.e., *Successes*), dyad-related features (i.e., *Repeated Relationships* and *Closeness Centrality*), and network-level attributes (i.e., *Transitivity).*

LIMITATIONS AND FUTURE RESEARCH

This study is limited in multiple ways. First, the analysis focused on examining relationships between project sponsors during the bidding and financial close stages of PPP projects. Network boundaries did not consider information regarding other project participants and PPP lifecycle phases. In a field characterized by poor transparency (De Biasio and Murray 2017; Siemiatycki 2015), data about PPP sponsors were found to be the most consistent and complete across proprietary and public databases. This helped to guarantee uniformity and comparability across networks by ensuring ties represented the same type of real-world interactions (i.e., sponsor-to-sponsor). Further research can focus on relationships among different PPP participants (e.g., lenders, advisors, and contracting authorities) through implementing two-mode network approaches (Pryke 2017).

Second, the proposed ERGMs were based on specific nodal, dyadic, and structural attributes, as these properties were considered to have potential effects on PPP sponsor networks. Although more attributes could have been incorporated into the models, the selection of such characteristics was based on a comprehensive literature review of the PPP body of knowledge. This was done under the premise that, despite the multiple differences across the studied countries, the three selected jurisdictions were capable of structuring analogous road PPPs according to project finance principles. Based on that, future research could expand the scope of this work by analyzing, for instance, the way institutional factors influence tie-formation processes by increasing or reducing competition among sponsors (Casady et al. 2018, 2019).

Finally, although some studies show that ERGMs are capable of examining network properties in a dynamic way (i.e., Temporal Exponential Random Graph Models); time-related features were not considered in this paper. Nevertheless, non-temporal ERGMs have proven to be a valuable source for obtaining a global perspective of network's behavior (Mele 2017; Rose Kim et al. 2016; Scott 2016; Silk and Fisher 2017), and Temporal Exponential Randon Graph Models have not been fully implemented in statistical packages (Leifeld et al. 2018). This, therefore, remains a research avenue that can be consolidated in the future.

CONCLUSIONS

This study examined tie-formation processes in networks of road PPP sponsors within Canada, Chile, and the US. The analysis was based on ERGM concepts and verified seven hypotheses directed to explore how road PPP investors established linkages among themselves across bidding and financial close stages. Model results revealed that, although each one of the studied networks is unique, tie-formation processes are influenced by similar effects at the dyad-, network-, and firm-levels.

The analysis suggests that investors participating in the studied road PPP markets are influenced by dyadic processes at the moment of forming prequalified bidding groups and preferred proponent consortiums. Specifically, results show that sponsors are very likely to establish recurrent relationships. This indicates that building trust between two participants is a very important factor when it comes to jointly bid for PPP projects. Such trust is built through repeated relationships and reinforced by attributes related to either the closeness centrality of players (in five out of the six studied networks) or the successful bidding record of investors (in the US PP network). A plausible explanation of this difference is that while American preferred proponents care more about positive bidding records when it comes to forming recurrent ties, sponsors in the other networks favor repeated interactions with investors capable of providing new contacts. However, what is clear for all markets and networks is that prior interlocks represent the main mechanisms through which sponsor groups are formed.

Apart from dyadic factors, the two studied network-based measures play distinctive but crucial roles across the analyzed networks. Given the positive and significant effect of *Transitivity* in all jurisdictions, it is clear that two unconnected sponsors are likely to establish a relationship if they have a third partner in common; reflecting the importance of forming relationships based on trust and shared values (i.e., my friend's friend is likely to be my friend). In line with that, considering the significant and negative coefficients associated with the *2-star* statistic, it is empirically evident that sponsors are not inclined to connect with other partners by relying on such partners' prominence (i.e., number of connections). As a result, sponsors are very likely to establish mutual relationships by using a common third-party as a proxy for an initial connection. This suggests that investors have a tendency to form triangle-like structures at the moment of creating SPVs as opposed to prioritizing preferential-attachment behaviors (i.e., the rich get richer). Consequently, similar to dyad-based results, this outcome confirms that sponsors' trustworthiness is one of their most valuable intangible assets.

In respect to firm-level properties, it is clear that such factors do not explain sponsors' behaviors as dyad- and network-based attributes do. Nationality-based features and expertise-related characteristics, for instance, only proved moderately important to explain the creation of PQB relationships in Canada and Chile, respectively. In this context, results revealed that having a successful bidding record was the main firm-specific attribute influencing tie-formation processes in most jurisdictions, as this property was supported in five out of six networks. This confirms that winning multiple projects is a valuable property, as it allows successful sponsors to show that they are reliable partners with whom other investors can successfully collaborate.

Overall, the application of ERGM procedures shows that relationships between PPP sponsors within the bidding and financial closure phases are mainly a function of trust-based mechanisms associated with multiple social network characteristics at different levels. This highlights the importance of relational procedures in the early stages of PPP projects, as sponsors need to connect with partners with whom they can efficiently design a proper tender strategy and, if successful, create suitable risk management mechanisms directed towards securing non-recourse debt resources and sharing/mitigating construction and operation risks. To do that, sponsors mostly rely on repeated relationships and transitivity mechanisms supported by closeness centrality properties and successful bidding records.

Accordingly, this study has managerial implications for public-private projects, PPP sponsors, and contracting authorities. First, considering that recurrent relationships and transitivity structures are the main drivers supporting sponsors' behaviors across the bidding and financial close stages; it is clear that there exist multiple opportunities for public-private initiatives to take advantage of the enhanced efficiencies, improved performance, and increased flexibilities derived from prior ties and project networks, as reported in the project-related literature (von Danwitz 2018; Ebers and Maurer 2016). Second, given the tendency to connect with familiar partners, PPP sponsors need to be aware that, although long-term trust-based relations are beneficial for improving organizational routines and facilitating integration (Bakker et al. 2016; Buvik and Rolfsen 2015), they may also be detrimental in terms of increasing transaction costs (Goerzen 2007) and hindering short-term strategic flexibility (Ebers and Maurer 2016). Third, taking into account that bidders tend to be reluctant to switch to different partners for every new PPP procurement process, government agencies need to recognize that such behaviors are not in line with promoting robust competition in PPP environments (Ebers and Maurer 2016; Siemiatycki 2011). As a result, based on the results of this study, PPP authorities should strongly incentivize the participation of new entrants to their jurisdictions in order to expand existing networks, diminish market concentration, and increase value for money.

Finally, this work contributes to the engineering and project management domains in multiple ways. First, it provides a characterization of the properties that influence the creation of linkages within each of the networks considered. Although several studies have analyzed the nature of relationships of equity providers in PPP projects, multiple scholars provide evidence that there is a gap in empirical studies focused on these topics (Burke and Demirag 2019; Warsen et al. 2018). Additionally, this study demonstrates the implementation of a new statistical approach, ERGM, and its application to better understand tie formation processes in PPP procurement. In this way, thanks to the use of ERGMs in this research, it was possible to examine interdependent factors without assuming independence among observations. Third, while several studies have analyzed social networks within public and private sectors in the past (Guevara et al. 2020b; Sedita and Apa 2015; South et al. 2018), most of them do not provide evidence of how private organizations establish linkages to participate in PPP tendering processes. As a result, this work enhances the PPP body of knowledge by gaining insight into the application of a new statistical methodology capable of explaining the characteristics associated with network formation in road PPP markets across Canada, Chile, and the US.

DATA AVAILABILITY

Some or all data, models, or codew generated or used during the study are proprietary or confidential in nature and may only be provided with restrictions (e.g., anonymized data). (Inframation Deals (2019), Public Works Financing (2019), and InfraPPP World (2020). The code formulated to implement the ERGM technique can be found in the Supplemental Data Section.

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976 TABLES

977 **Table 1. PPP projects under study**

	PPP USA		PPP Chile		PPP Canada
ID	**Name**	**ID**	**Name**	**ID**	**Name**
U1	SR 91 – California (1993)	CH1	CH-156 Concepción-Coihue (1994)	C1	Confederation Bridge (1993)
U2	Dulles Greenway (1993)	CH2	Melon Tunnel Valparaíso (1995)	C2	Fredericton-Moncton H (1998)
U3	SR 125 South Highway (2003)	CH3	Route 78 (1996)	C3	Sierra Yoyo Desan Road (2004)
U4	Chicago Skyway (2005)	CH4	Route 5 Talca-Chillán (1996)	C4	Kicking Horse Canyo (2005)
U5	Virginia I-895 / Pocahontas (2006)	CH5	Route 5 Santiago-Los Vilos (1996)	C5	Sea-to-Sky Highway (2005)
U6	Indiana Toll Road (2006)	CH6	North. Access to Concepción (1997)	C6	S-E Edmonton Ring Road (2005)
U7	I-495 Capital Beltway (2007)	CH7	Route 5 Los Vilos-La Serena (1997)	C7	William R.Bennett Bridge (2005)
U8	SH-130 (2008)	CH8	Andes Highway Santiago-Colina (1998)	C8	Golden Ears Bridge (2006)
U9	I-595 Corridor Roadway (2009)	CH9	Route 5 Chillan-Collipulli (1998)	C9	Autoroute A25 (2007)
U10	Miami Port Tunnel (2009)	CH10	Route 5 Temuco-Río Bueno (1998)	C10	Deh Cho Mackenzie River Bridge (2007)
U11	North Tarrant Exp. (2009)	CH11	Route 5 Los Lagos-Río Bueno (1998)	C11	Stoney Trail NE Calgary (2007)
U12	IH-635 - LBJ Freeway (2010)	CH12	Route 5 Santiago-Talca (1999)	C12	Autoroute A30 (2008)
U13	PR-22,PR-5 Toll Road (2011)	CH13	Route 5 Collipulli-Temuco (2001)	C13	NWAnthony Henday (2008)
U14	I-95 HOV/HOT Lanes (2012)	CH14	Costanera Highway (2001)	C14	Chief Peguis Trail Extension (2010)
U15	Midtown Tunnel (2012)	CH15	Santiago Central Highway (2001)	C15	Disraeli Bridges (2010)
U16	Presidio Parkway (2012)	CH16	Central Coastal Highway (2001)	C16	Route 1 Gateway Highway (2010)
U17	East End Crossing Bridge (2013)	CH17	Route 78 Grecia Vespucio Avenue (2002)	C17	South East Calgary Ring Road (2010)
U18	Goethals Bridge (2013)	CH18	Talcahuano Interport Route (2002)	C18	South Fraser Perimeter Road (2010)
U19	North Tarrant 3A-3B (2013)	CH19	Melipilla Bypass (2003)	C19	Windsor-Essex Parkway (2010)
U20	I-4 Ultimate (2014)	CH20	Andes-Peñablanca (2004)	C20	Billy Bishop Toronto (2012)
U21	Indiana I-69 (2014)	CH21	Vespucio El Salto Kennedy (2005)	C21	Highway 407 Extension (2012)
U22	SH 183 - Dallas-F.W. (2014)	CH22	North-East Access Santiago (2007)	C22	Northeast Anthony Henday (2012)
U23	US 36 (2014)	CH23	Access road Arturo Merino Airport (2008)	C23	Highway 407 East Phase 2 (2015)
U24	I-77 HOT Lanes (2015)	CH24	Route 5 Vallenar-Caldera (2009)	C24	New Champlain Bridge (2015)
U25	Pennsylvania Rapid Bridge (2015)	CH25	Antofagasta Regional H. (2010)	C25	Regina Bypass (2015)
U26	Southern Ohio Highway (2015)	CH26	Route 5 Puerto Montt-Pargua (2010)	C26	Saskatoon Bridges (2015)
U27	SH 288 (2016)	CH27	Road 160-Tres Pinos-Coronel (2010)	C27	Southwest Calgary Ring Road (2016)
U28	Indiana State Street Redevelopment (2016)	CH28	Concepcion-Cabrero Road (2011)	C28	Highway 427 Extension (2017)
U29	Colorado I-70 East (2017)	CH29	Iquique Access Road (2011)	C29	Gordie Howe International Bridge (2018)
U30	I-395 –Virginia (2017)	CH30	Route 5 Serena-Vallenar (2012)	C30	Northwest Territories (2019)
U31	Transform 66 (2017)	CH31	Serena-Ovalle (2013)		
U32	Michigan I-75 (2018)	CH32	Route del Loa (2018)		

Note: information obtain from Guevara et al.(2020b).

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Table 2. PPP Investors

Canada: Participation as Bidder		Canada: Participation as Preferred Proponent	
Sponsor	**Project ID (C)**	**Sponsor**	**Project ID (C)**
SNC-Lavalin	1,3,4,7,9,11,12,13,15,17,18,21,22,23,24,25	ACS	2,12,18,19,22,24,28,29
Kiewit	2,3,4,5,8,11,14,15,18,19,22,24,25,27,30	Miller	2,5,8,28
Macquarie	3,5,6,8,9,11,12,17,19,20,21,22,24	Bilfinger	8,11,13,26
Aecon	5,8,19,20,21,23,24,25,27,28,29	SNC-Lavalin	7,17,21,24
Bilfinger	6,8,11,13,17,18,19,26,28,29	Kiewit	3,5,27,30
ACS	2,12,18,19,22,23,24,28,29	Acciona	12,17,19
Hochtief	17,19,22,24,25,26,27	Vinci	1,2,25
Acciona	9,12,17,19,24,26,27	Graham	11,25,26
Cintra-Ferrovial	12,18,21,23,28	Ledcor	3,18,27
Aecom	14,16,19,25,26	Macquarie	5,9
Vinci	1,2,5,25,27,29	Cintra-Ferrovial	21,23
Miller	2,5,8,9,28,16	Hochtief	22,24
Graham	5,11,25,26	Fluor	19,29
Ledcor	3,18,27	Meridiam	22,27
Chile: Participation as Bidder		**Chile: Participation as Preferred Proponent**	
Sponsor	**Project ID (CH)**	**Sponsor**	**Project ID (CH)**
ACS	2,15,17,19,20,21,23,25,26,28,29	Sacyr	7,16,26,28,29,30
Hochtief	2,15,17,19,21,23,25,26,28,29	Belfi	1,15,17,21
Belfi	1,2,15,16,17,19,21,25,28,29,31	Cintra-Ferrovial	9,10,12,13
Besalco	17,18,19,20,23,25,26,28,29,31	Endesa	2,3,8
Itinere	15,16,17,22,24,26,28,29	ACS	15,17,21
Cintra-Ferrovial	2,4,9,10,11,12,13,28	Itinere	16,22,26
OHL S.A	16,17,20,21,24,28,30	Besalco	18,19,31
Brotec	15,16,28,29,31	Skanska	15,17,25
TECSA	5,11,13,14,18	ACS	15,17,21
Mendes Junior	12,16,17,18	Hochtief	17,21
Acciona	15,16,17,20	Delta	4,10
Astaldi Construction	15,17,20	Acciona	16,27
Necso	12,17,20	OHL S.A	20
Taurus Holdings	19,22	Grupo Costanera	23
USA: Participation as Bidder		**USA: Participation as Preferred Proponent**	
Sponsor	**Project ID (U)**	**Sponsor**	**Project ID (U)**
Cintra-Ferrovial	4,6,8,11,12,19,22,23,24,26,27,29,31	Cintra-Ferrovial	4,6,8,11,12,19,24,31
Meridiam	10,11,16,18,19,20,21,22,24,25,29,31	Meridiam	10,11,12,16,19,29,31
Macquarie	3,4,5,6,9,12,15,18,20,21,22,27,28	Macquarie	3,4,5,6,9,15,18
Fluor	7,9,14,20,22,25,29,30,31	Kiewit	1,18,22,29
John Laing	9,17,18,20,24,25,29,31,32	Transurban	5,7,14,30
ACS	9,12,16,17,18,26,27,29	John Laing	20,24,31,32
Kiewit	1,12,17,18,20,22,25,29	Fluor	7,14,30
InfraRed Capital Partners	17,20,24,25,26,27,29,31	ACS	9,26,27

Skanska	2,9,15,17,18,20,29,31	DPPF	11,12,19
OHL S.A	9,11,20,22,24,27	Plenary North America	23,25,28
Plenary North America	21,23,25,26,28,29	InfraRed Capital Partners	26,27
Walsh Group	17,20,21,25,26,28	Skanska	15,2
Transurban	4,5,7,14,30,31	APG Group	19,31
Zachry American	8,11,12,17	Walsh Group	17,25

Note: information obtained from proprietary database as described in the text.

Table 3 Network properties

Parameter		Description	Social process analyzed
Baseline	**Function**		
Tie	$S_1(y,x)$	Baseline defining the probability of a tie between two sponsors, without considering attributes. **Statnet term**: sum	General tendency to form ties without consideration for attributes.
Actor-level properties			
Nationality	$S_4(y,x)$	Categorical variable for each firm, sponsors take the value 0 if the firm is a domestic sponsor,1 if the firm is a local sponsor, and 3 otherwise. **Statnet term**: absdiffcat	Ties between local, domestic, and foreign sponsors.
Expertise	$S_4(y,x)$	Categorical variable for each firm, sponsors take the value 1, if the firm has an operational construction branch, and 0 otherwise. **Statnet term**: absdiffcat	Ties between EPs with and without construction branches.
Successes	$S_5(y,x)$	Discreet numerical variable for each firm, denoting the number of successful bids. **Statnet term**: nodecov	Ties between sponsors in accordance with their successes.
Dyad-level properties			
Closeness centrality	$S_5(y,x)$	Tendency of the two sponsors to group together in accordance with the value of their continuous or discreet attributes. **Statnet term**: absdiff	Ties between sponsors in accordance with their closeness centrality values.
Repeated relationships	$S_4(y,x)$	Tendency of the two sponsors to form recurrent ties. **Statnet term**: edgecov	Ties between sponsors in accordance with repeated relationships in past processes.
Network-level properties			
Transitivity	$S_3(y,x)$	The tendency of three soponsors to create a collaboration triad for PPP procurement. **Statnet term**: transitiveties	Ties between sponsors to create a triad for PPP procurements.
2-Star	$S_2(y,x)$	Tendency of a network to form stak-like structures between participants. **Statnet term**: nodecovar	Ties between sponsors to form connections around a central node.

Note: definitions obtained from Gonzalez and Verhoest (2018), Kim et al. (2016), and Hunter et al (2018).

Table 4 ERGM results – Preferred Proponent Networks

	Canada PP		USA PP		Chile PP	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Ties	-6.10***	-6.51***	-3.79***	-3.80***	-5.18***	-6.62***
Endogenous factors						
Nationality 1.1	0.43	0.68	-0.13	-0.19	-0.19	0.03
Nationality 1.2	0.66	0.88	-0.08	-0.18	-52.22	-33.41
Nationality 1.3	0.17	0.13	-0.96	-1.05	0.01	0.19
Expertise	0.18	0.36	-0.09	0.00	0.31	-0.04
Successes	0.13	0.43***	0.19***	0.32***	0.12	0.22*
Closeness centrality	4.29***	4.34***	0.03	0.35	6.14**	9.45**
Repeated relationships	1.72***	2.44***	2.25***	2.43***	2.71***	4.07***
Network-level factors						
Transitivity		1.04**		0.45*		1.34***
2-star		-0.31***		-0.21***		-0.24**

Significance codes: ***p <0.001 **p<0.01 *p<0.05 +p<0.1

Table 5 ERGM results – Prequalified Bidder Networks

	Canada PQB		USA PQB		Chile PQB	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Ties	-8.03***	-8.18***	-4.85***	-5.19***	-5.37***	-5.77***
Endogenous factors						
Nationality 1.1	0.33*	0.53*	0.03	0.01	-0.07	-0.01
Nationality 1.2	0.23	0.35	-0.45	-0.54	-0.08	-0.01
Nationality 1.3	0.20	0.37	-0.03	-0.04	-0.21	-0.09
Expertise	0.09	0.09	0.09	0.22	0.02	-0.20*
Successes	0.05	0.04	0.08**	0.10*	0.02	0.07+
Closeness centrality	6.13***	5.00***	2.55***	2.66***	5.78***	4.93***
Repeated relationships	2.03***	2.94***	2.61***	3.15***	3.55***	5.13***
Network-level factors						
Transitivity		0.70***		0.54***		1.44***
2-star		0.00		-0.03		-0.11***

Significance codes: ***p <0.001 **p<0.01 *p<0.05 +p<0.1

Table 6. Validation Procedures for ERGM results - Preferred Proponents

	Canada PP		USA PP		Chile PP	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Akaike information criterion	721.9	613.9	608.3	618.7	523.5	505.8
Bayesian information criterion	688.3	571.8	575.2	577.3	492.6	467.2
SGOF	0.05(-0.33,0.35)		0.03(-0.59,0.40)		0.22(-0.21,0.47)	

Table 7. Validation Procedures for ERGM results - Prequalified Bidders

	Canada PQB		USA PQB		Chile PQB	
	Model 1	**Model 2**	**Model 1**	**Model 2**	**Model 1**	**Model 2**
Akaike information criterion	2289	1973	2383	2086	2726	2412
Bayesian information criterion	2246	1919	2340	2032	2683	2359
SGOF	0.72(0.61,0.81)		0.59(0.43,0.73)		0.04(-0.41,0.42)	