Centrally administered state-owned enterprises’ engagement in China’s public–private partnerships: a social network analysis

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ABSTRACT
A salient characteristic of China’s public–private partnerships (PPPs) is the deep involvement of state-owned enterprises (SOEs), particularly those administered by the central/national government (CSOEs). In this research social network analysis (SNA) was used to examine the role of different actors in transport and environmental protection PPPs in China in the period 2012–17. The results largely confirm the resource-based view and resource-dependency theory, showing that while CSOEs are dominant in both sectors, their dominance and control is greatest in transport sector projects that are more dependent on their accumulated experience, expertise, human capital assets and management skills, that their dominance has increased over time, and that it is aligned with the provincial distribution of Chinese CSOEs.

KEYWORDS
public–private partnerships, state-owned enterprises, resource-based view, resource-dependency theory, social network analysis

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RESUMEN
Participación de empresas estatales administradas centralmente en sociedades públicas–privadas: análisis de las redes sociales. Area Development and Policy. Una característica destacada de las sociedades públicas–privadas en China es la intensa participación de las empresas estatales, sobre todo las que están administradas por el Gobierno central/nacional. En este estudio utilizamos un análisis de las redes sociales para examinar la función de los diferentes protagonistas en las sociedades públicas–privadas con respecto al transporte y la protección medioambiental en China durante el periodo de 2012 a 2017. Los resultados confirman en gran medida la perspectiva basada en los recursos y la teoría de dependencia de los recursos y muestran que, si bien las administraciones centrales/nacionales dominan en ambos sectores, su dominio y control son mayores en los proyectos del sector de transporte que dependen más de su experiencia acumulada, conocimientos especializados, bienes de capital humano y capacidad de gestión. Asimismo, este dominio ha aumentado con el tiempo y corresponde a la distribución provincial de las administraciones centrales y nacionales de China.

PALABRAS CLAVE
sociedades públicas–privadas, empresas estatales, perspectiva basada en los recursos, teoría de dependencia de los recursos, análisis de redes sociales

АННОТАЦИЯ
Участие централизованно управляемых государственных предприятий в государственно–частных партнерствах в Китае: общественно–сетевой анализ. Area Development and Policy. Характерной чертой государственно–частного партнерства (ГЧП) в Китае является активное участие государственных предприятий (ГП), особенно тех, которые находятся в ведении центрального/национального правительства (ЦГП). В этом исследовании общественно–сетевой анализ (Social Network Analysis, SNA) был использован для изучения роли различных субъектов в ГЧП на транспорте и охране окружающей среды в Китае в 2012–17 годах. Полученные результаты в значительной степени подтверждают ресурсную точку зрения и теорию ресурсной зависимости, показывая, что, хотя ЦГП доминируют в обоих секторах, их доминирование и контроль наиболее велики в проектах транспортного сектора, которые в большей степени зависят от их накопленного опыта, экспертных знаний, человеческого капитала и управленческих навыков; их доминирование со временем возросло и согласуется с провинциальным распределением китайских ЦГП.

КЛЮЧЕВЫЕ СЛОВА
государственно–частное партнерство, государственные предприятия, ресурсный подход, теория ресурсной зависимости, анализ общественных сетей

INTRODUCTION
The past decades have seen an increasing interest in public governments collaborating with non–public sectors, such as private corporations and non–profit organizations, to deliver public goods and services. In China this phenomenon is particularly marked as by the end of 2018 there were 8654 public–private partnership (PPP) projects valued at nearly RMB13.2 trillion (approximately US$1.89 trillion) (China Public–Private Partnerships Center, 2018). China has become the country with the largest number of PPP projects and the highest PPP investment amount (Zhao et al., 2018).
In the Chinese context, PPPs refer to long-term contractual collaboration between the
governments and societal capital organizations in various areas of public service provision. The
societal capital organizations consist of state-owned enterprises (SOEs), privately owned
companies and foreign businesses. The involvement of SOEs has become a salient character-
istic of China’s PPPs. SOEs are state owned or controlled and, especially in the case of
centrally administered SOEs (CSOEs) which are affiliated with and controlled by China’s
central/national government (other SOEs are directed by provincial or municipal govern-
ments), they leverage ample resources, possess extensive political and financial access com-
pared with their private counterparts. Different from SOEs and CSOEs, private firms in
China usually have limited financial capacities and access to resources, and thus higher
financing costs than CSOEs (Cheng et al., 2016; De Jong et al., 2010; Mu et al., 2011).
Given the low rates of return and the long duration of cost recovery in PPPs, high financing
costs may render many PPP opportunities less profitable, and then restrict private firms’
participation in PPPs. A total number of 981 societal capital organizations had participated
in 597 national PPP demonstration projects by the end of 2017. Among these organizations
there were 569 SOEs, accounting for nearly 60% of all the societal capital partners (China
Public–Private Partnerships Center, 2018).

The overall question of this paper is whether CSOEs exercise a dominant influence and control
over China’s PPPs because of their superior access to and control of resources. To answer this
question, insights from the resource-based view (RBV) framework and resource-dependency theory
(RDT) are combined. The RBV serves as the foundation for understanding and analysing various
participants’ motivations, preferences and priorities in PPP formation (Barney, 1991; Eisenhardt &
Schoonhoven, 1996). CSOEs, other SOEs and non-SOEs (private corporations) possess distinct
assets and resources that may be respectively sought after in the establishment of PPPs by various
public governments which may have unique needs for various types and/or amount of resources. In
the light of CSOEs’ superior access to and control over strategic assets, they may then be preferred
partners in PPP collaboration and partnering. RDT suggests and predicts a power asymmetry in
partnering relationships if and when some participants depend heavily on other participants’
resources (Pfeffer & Salancik, 2003). The overall hypothesis, informed by RBV and RDT, is that
CSOEs, being resource-abundant PPP partners, tend to exert a dominant influence in PPP
relationships and exercise control power over other participants. The overall hypothesis is further
decomposed and tested across industrial sectors, over time and across geographical space.

Methodologically, a social network analysis (SNA) is applied to examine PPP network
structures and positions in two sectors, namely, transport and environmental protection, in the
period of 2012–17 and across all Chinese provinces. A SNA approach is appropriate because
local governments and societal capital partners are interdependent and interconnected in a
governance network in which resources flow among PPP participants as they cluster to share
and exchange resources. Furthermore, SNA has advantages when compared with approaches
in other existing studies in that it investigates the entire PPP governance network and
examines PPP participants’ embedded network positions. Existing studies have generally
focused on individual, isolated PPP transactions and overlook interdependence and intercon-
nection across PPP transactions and among the PPP participants.

The paper advances scholarly understandings of CSOEs’ engagement in China’s PPP
formation. Theoretically, the RBV framework, which is often used to explain private sector
motivations in relation to external partnerships (i.e., whether or not to establish a partnership),
is extended to examine governments’ priorities and preferences (i.e., with whom to partner).
Further, the RDT approach is introduced in China’s PPP context for a better understanding
of asymmetrical relational connections in PPP networks as a consequence of local govern-
ments’ high dependence on resources and assets possessed by CSOEs. The methodological
contribution derives from the holistic network approach capturing and measuring
interdependence and interconnection among PPP participants. This complements, but improves on, the existing literature that relies solely on descriptive statistics of CSOEs’ involvement in individual PPP projects.

In addition, data-wise, this paper uses a novel data source for exploring CSOEs’ roles in PPP networks. In a response to China’s national government’s emphasis on developing PPPs, in 2015 China’s Ministry of Finance (MOF) created a public database to improve transparency in China’s PPP development. This new database includes PPP projects across all sectors, invested in by either private firms or SOEs. Previous qualitative research on PPPs in China’s context primarily collected data from The World Bank’s Private Participation in Infrastructure Project Database Weblink: https://ppi.worldbank.org/en/ppidata (Wang et al., 2018; Zhang, 2015). However, this database is confined to infrastructure projects and projects in which mainly private firms invest.

This novel data set and network analysis enable this research to contribute to the emerging field of computational socioeconomics and policy analytics.1 This research also seeks to illustrate the ways in which connections between governments and societal capital organizations as well as CSOEs’ dominance are distributed over China’s complex geographical landscape by integrating social network data with geographical information system (GIS) techniques.

This paper analyses CSOEs’ influence and control power in PPP networks in two different industrial sectors: over time in 2012–17 and across all Chinese provinces. Participants’ influence and importance within a network is measured by the extent to which they are connected to well-connected nodes. Control power refers to a participant’s control over the network by bridging various participants and facilitating information exchange. The multifaceted analyses will greatly enrich our understandings of the involvement and roles of CSOEs in China’s PPP formation and network.

The remainder of the paper is structured as follows. The resource-based theoretical framework of PPPs is next introduced, and is followed by an overview of China’s PPP development. Hypotheses pertaining to CSOEs’ dominant roles in PPP networks across sectors, over time and across geography are developed. The results of an SNA using the PPP data collected from the China Public–Private Partnerships Centre (CPPPC) are presented, identifying the influence and control power of CSOEs in PPP networks. Empirical analysis and findings on the influence and control power of CSOEs as well as the results of the robustness check are presented and discussed, and conclusions and policy options for future PPP development are developed.

RESEARCH BACKGROUND AND THEORETICAL FRAMEWORK: A RESOURCE POSSESSION AND ACQUISITION PERSPECTIVE ON PPPS

PPPs bring together resources from both public and private sectors (Hodge & Greve, 2005; Klijn & Teisman, 2003). Heterogeneous possession and diverse acquisition of resources and different degrees of dependence on them, as embodied in the RBV and RDT, characterize the formation of PPP networks as well as the relationships of network participants. RBV focuses on an internal analysis of organizations’ strengths and weaknesses which are defined as the ‘resources’ of a given organization (Barney, 1991). Such resources may be tangible, such as financial, physical or human capital, but may also include intangible resources such as knowledge (Grant & Baden-Fuller, 2004). Barney (1991, p. 99) contends that the ‘resources are heterogeneously distributed across firms and these differences are stable over time’. By forming strategic alliances, organizations can gain access to others’ valuable resources, facilitate resource integration and achieve mutual benefits (Das & Teng, 2000; Eisenhardt & Schoonhoven,
Such strategic alliances are characterized by mutual recognition and understanding of the long-term dependence of success on each partner’s resources (d’Alessandro et al., 2013; Roumboutsos & Chiara, 2010).

PPPs as strategic alliances are built upon mutual benefits to both public and societal capital partners. For governmental participants, PPPs permit the acquisition of financial capital, technical expertise and know-how, enabling them to provide public services more effectively and/or efficiently (Kivleniece & Quelin, 2012; Martin, 2018). For societal participants, in addition to projected profits, the governments usually provide political support, government sponsorships, financial assistance, government guarantees, tax exemptions or reductions, and new market opportunities, reducing possible losses and ensuring remuneration. In a study of the Beijing Metro Line 4 Project, Liu et al. (2016) suggest that societal capital organizations may even seek market reputation and legitimacy at the expense of short-term profits.

While RBV explains collaborative motives deriving from resource-sharing and mutual benefits, RDT emphasizes the power asymmetries based on the dependence of organizations on resources that are unequally distributed (Pfeffer & Salancik, 2003). RDT suggests that there are potential power imbalances between PPP participants within strategic alliances, because their possession of resources, control over resource flows and dependence on resources differ. Klijn and Koppenjan (2016) distinguish five main types of resources: (1) financial resources including money and budgets; (2) production resources such as advanced equipment and human capital; (3) competencies such as formal authority; (4) knowledge such as technical expertise and know-how; and (5) legitimacy such as political support. Any public or societal capital organization, which owns resources to which others do not have access, will likely be a sought-after partner. This organization, naturally and consequently, will exert a dominant influence and exercise power over its partners. Singh and Prakash (2010), by studying PPPs in health service delivery in India, found that governments are influential because their partners, mainly small non-governmental organizations (NGOs), are dependent on governmental resources and have to comply with all administrative requirements and regulations.

D dominance and power imbalances among PPP participants can be indicated and measured using SNA, specifically, governance networks for exchanging resources within strategic alliances. Klijn and Koppenjan (2016) define governance networks as social relations between mutually dependent actors which cluster to share and exchange resources. Based on collaborative relationships between governments and societal partners in PPPs, a network of interdependent actors can be discerned (Hodge & Greve, 2007; Klijn & Koppenjan, 2000; Koppenjan, 2005). Each organization serves as a node and each pair-wise relationship derived from an actual contractual PPP transaction serves as an edge between two nodes. The network position of a given participant in the governance network is primarily determined by its control over and dependence on resources (Benson, 1975).

In SNA, the network position of nodes exhibiting prominence, popularity or power is normally characterized by network centrality (Wasserman & Faust, 1994). Network centrality ranks nodes based on their connections to other nodes in the network (Lü et al., 2016). Two network centrality measures were used, specifically, eigenvector centrality and betweenness centrality. Eigenvector centrality represents the influence of a node in the network. It assesses the extent of a node’s connection particularly to well-connected nodes (Borgatti, 2005). Hence, a node’s influence is determined not only by its number of direct neighbours but also by the influence of its neighbours (Lü et al., 2016). Additionally, betweenness centrality assesses the degree to which one node connects the shortest path between other nodes (Freeman, 1977). Nodes with high betweenness centralities have high control power and act as brokers on bridges connecting other organizations in the network (Wu et al., 2018).
China’s PPP development

The development of PPPs in China has experienced significant fluctuation. China’s legal and regulatory framework for PPPs was established in the 1980s when the central government encouraged and promoted foreign investment in public infrastructure development (Zhao et al., 2018). Promotion of the involvement of foreign investment at the time was designed to supplement local governments’ own as-yet-limited fiscal capacity in infrastructure construction in order to meet the growing demand for local economic development after China’s ‘reform and open-up’ policy. However, PPP engagements with foreign investment was interrupted by the Asian Financial Crisis in 1998 when foreign capital was scarce (Zhang et al., 2015).

The second wave of PPPs in China started in 2000 when both domestic and foreign private capital were encouraged to support rapid urbanization in China. The Beijing Metro Line 4 project and the main stadium for the Beijing 2008 Summer Olympic Games were two successful examples leading the second wave of PPP projects. However, the growth of PPP projects was suspended after the Global Economic Crisis in 2008 when many private firms went bankrupt. Instead, local governments were encouraged to borrow through the quasi-governmental entities, that is, local government financing vehicles, as well as to issue governmental bonds to sustain infrastructure development (Gao et al., 2019; Mu et al., 2011). Debt finance started as a supplement to China’s local governments’ own-source fiscal revenues, but saw a tremendous growth after the 2008 Global Economic Crisis when the central government massively expanded credit to stimulate economy (Zhao et al., 2018).

The most recent PPP surge in China started in 2014 when the government took stringent measures to contain China’s local municipalities’ alarmingly high debts. Municipal debt and land transfer fees had been the predominant means for financing local and municipal infrastructure and services before 2014. In that year local debts reached an alarming level and threatened fiscal sustainability, and so China’s central government restricted local governments from borrowing and capped local debt (Thieriot & Dominguez, 2015). Also, with less available land remaining, revenues from land leasing were not sustainable (Liu, 2019). In the meantime, PPPs naturally became an alternative financing source for profitable public projects. Figure 1 reports trends in PPP projects and investment amounts in 2012–17. Tan and Zhao (2019) suggest that the sudden spike of PPPs in 2015, as shown in Figure 1, corresponded with the central government’s 2014 decision to curb the growth of local debts in light of considerable risk of local government insolvency.

Roles of SOEs in PPPs

Local governments and societal capital organizations in China exchange resources, establish strategic alliances and achieve mutual benefits by establishing PPPs. PPPs in China are characterized by the extensive involvement of SOEs. The strengths of SOEs, as major societal capital partners, are derived from five factors. (1) SOEs have close ties to the government. Close relationships may offer SOEs greater access to, and more opportunities to participate in, PPP projects with a strong cash flow, and may also indirectly benefit local governments that collaborate with SOEs in PPP projects (Tan & Zhao, 2019; Thieriot & Dominguez, 2015). (2) SOEs tend to have stronger financial capacities than private firms. Commercial banks prefer to provide loans to SOEs as they are endorsed by the governments (De Jong et al., 2010). (3) SOEs may be preferred partners in forming PPPs because of their accumulated experience, expertise, human capital assets and management skills (Mu et al., 2011). (4) SOEs are more stable partners in contrast to private firms. Regardless of government transition, leadership mobility and policy change, SOEs may be far more likely than non-SOEs to carry out PPP projects which usually last more than ten years (Mu et al., 2011; Tan & Zhao, 2019). (5) SOEs are likely to enter a PPP contract with a lower profit expectation than private firms,
because SOEs also bear political and social responsibilities in addition to economic missions (Li & Zhang, 2010).

The capacity of SOEs to control and influence resource flows is amplified especially in CSOEs. By the end of 2017, there were a total of 96 CSOEs in China, all of which were ‘extremely large firms concentrated in resource-intensive industries’ (Eaton & Kostka, 2017, p. 2), such as ‘finance, power and utilities, petrochemicals and energy, and aircraft and telecommunications’ (Wang et al., 2014, p. 232). Recognized as the backbone of the economy, CSOEs have more access to strategic resources than SOEs (Huang et al., 2017). In addition to strong financial capacities, some CSOEs have set up their own engineering design and research institutes to focus on research and development (R&D) processes to improve their expertise. In contrast, local governments only exercise control over the limited resources that they can provide to local SOEs (Li et al., 2014). Hence, CSOEs have greater access to and control over, resources compared with SOEs and other societal capital partners.

Acquiring financial resources and overcoming financing constraints, as emphasized by the RBV, have been predominant drivers of China’s local governments’ enthusiasm for establishing PPPs. Figure 2 presents a conceptual framework, derived from the RBV and RDT, for analysing China’s PPPs. PPPs may be initiated when local governments and/or societal capital organizations seek to access each other’s unique resources. On the one hand, local governments gain access through societal capital organizations to financial capital, physical resources and knowledge or know-how which are necessary for governments to deliver public infrastructure and services. Such public infrastructure would not have been completed in the

Figure 1. Total number and investment of public–private partnership (PPP) projects, 2012–17. Source: National PPP database, China’s Ministry of Finance.
Figure 2. Theoretical framework of public–private partnerships (PPPs) in China from a perspective of resource possession.
absence of partnering with societal capital organizations. Delivering public infrastructure such as highways and railroads and harnessing such infrastructure for local economic development are primary measures used to assess local governments’ effectiveness, gain an edge in intercity competition, and make decisions about career advancement of local officials (Tan & Zhao, 2019; Zhu & Jiao, 2012). On the other hand, societal capital organizations will not only obtain remuneration and profits for designing, constructing, and/or operating PPP projects, but also gain legitimacy by associating and partnering with local governments (Eisenhardt & Schoonhoven, 1996; World Bank, 2017). Access to political and policy authorities will greatly elevate societal capital organizations’ competitive positions and further development. Furthermore, as the RDT suggests, different types of societal capital organizations’ heterogeneous possession of resources may lead to power imbalances among organizations. Organizations that possess resources and/or are not dependent on others’ resources will exercise control power over the network, though these relationships may vary across different sectors as sectoral resource demands vary.

RESEARCH QUESTION AND HYPOTHESES

This research asked whether CSOEs would exercise a greater influence and control power than other participants in PPP governance networks. The overall hypothesis was that CSOEs have a dominant influence and control power. This overall hypothesis was decomposed and tested across industrial sectors, throughout time and space geography.

Across various industrial sectors, the demand for the types as well as the magnitude of resources varies. CSOEs’ influence and control power in PPP networks may vary accordingly in different industries. Das and Teng (2000) broadly classify the resources into property and knowledge based. Property-based resources include financial, physical and human capital, while knowledge-based resources refer to the expertise and skills that are usually intangible. The key distinction between property- and knowledge-based resources is the degree to which these resources can be protected from potential appropriation by alliance partners. Different types of societal capital organizations may vary in their ability to influence flows of the two distinct types of resources.

CSOEs in China are designated to produce the public goods related to national security and the national economy. Thus, they have superior access to financial, physical and human capital, and monopolize key national sectors (Hubbard, 2016). CSOEs can primarily mobilize and exchange resources that are property based and capital intensive. Therefore, in property-based industrial sectors that require tremendous financial, physical and human capital, such as transport and utilities, CSOEs might be expected to assume a much stronger and influential network position. Private firms generally lack property-based resources (De Jong et al., 2010; Mu et al., 2011), and hence may have a stronger motivation to improve technology, optimize management and lower costs. Private firms tend to possess knowledge-based resources and are likely to play a significant role in the knowledge-based sectors. Therefore, the first sub-hypothesis pertaining to cross-sectoral variations in CSOEs’ dominant roles is that:

Sub-hypothesis 1: CSOEs’ influence and control power in PPP networks are greater in sectors that rely more on property-based resources (transport) than in sectors dependent on knowledge-based resources (environmental protection).

Temporally, CSOEs’ influence and control power in PPP governance networks may have increased. There may be a learning process as local governments match their demands with resources provided by different types of societal capital organizations. By forming a strategic alliance, PPP participants aim to access the others’ unique resources. The success or performance of a strategic alliance is likely to be influenced by the learning process deriving from interaction among partners (Zollo et al., 2002). Based on continuous collaborations, the
CSOEs’ competitive advantages may be expected to increase. Consequently, CSOEs’ dominance in PPP networks may increase over time. Therefore, the second sub-hypothesis pertaining to variations in CSOEs’ dominant roles over time is:

Sub-hypothesis 2: CSOEs have greater influence and control power in PPP networks over time in both transport and environmental protection sectors.

From a geographical perspective, CSOEs are not evenly distributed across Chinese provinces. It is natural that CSOEs’ influence and control power are greater in provinces that have higher concentrations of CSOEs, mainly because of spatial proximity which reduces information search costs and encourages within-province PPP collaboration. Such a geographical constraint may, however, be less restrictive for sectors such as environmental protection that rely greatly on knowledge-based resources, and where local governments may have greater flexibility and discretion and therefore may be able to cooperate with non-CSOEs with strategic access to key technology and skills. In contrast, in the sectors that rely on property-based resources, proximity may lead local government to collaborate with CSOEs and their subsidiaries. Thus, the third sub-hypothesis pertaining to geographical variations in CSOEs’ dominant roles is:

Sub-hypothesis 3: CSOEs’ influence and control power in PPP networks are less constrained by the provincial distribution of CSOEs in the environmental protection sector than in the transport sector, that is, local governments may have greater flexibility and discretion and therefore may be able to seek non-CSOEs in the environmental protection sector than in the transport sector.

DATA AND METHODS

Data on PPP projects during 2012–17 in the transport and environmental protection sectors were collected from the public data set of the CPPPC. This data set is managed by the MOF, which is the official organization authorized by the central government to ensure the success of PPP projects in China.

The transport sector was chosen as a property-based sector and environmental protection as a knowledge-based sector to test the above hypotheses. According to the statistics from the China Public–Private Partnerships Center (2018), the top five sectors adopting PPPs are utilities, transport, environmental protection, urban development and education. Transport infrastructure projects, such as subway lines and huge bridges, are usually large scale and involve complicated technology. PPP projects pertaining to transport infrastructure require intensive expertise, experience, management skills, and financial and human capital (De Jong et al., 2010; Mu et al., 2011). The average investment for a transport infrastructure PPP project was nearly RMB700 million (approximately US$107.13 million) (Shao, 2018). As a result, a large portion of infrastructure construction enterprises in China are CSOEs and SOEs that have sufficient property-based resources. Taking the Beijing Metro Line 4 project as an example, the societal capital partner was a joint-venture composed of Mass Transit Railway owned by the Hong Kong government, Beijing Capital Group Company Ltd and Beijing Infrastructure Investment Company Ltd, which are two SOEs owned by the Beijing Municipality Government (Liu & Wilkinson, 2013). On the contrary, PPP projects pertaining to environmental protection usually involve high-tech activities (Lee, 2010). Private firms are likely to have more opportunities and play a significant role in the environmental protection sector because they may possess technical know-how, though they may lack credentials, experience and financial capital for infrastructure construction (De Jong et al., 2010; Mu et al., 2011).

SNA was conducted to explore and compare the characteristics of transport and environmental protection PPP networks. The units of analysis were pair-wise PPP transactions. All governments and societal capital organizations were nodes in the network, and linkages or
edges referred to contractual interactions between city governments and societal capital partners. The contractual relationships among various governments and societal capital organizations were extracted from actual PPP agreements and contracts, which are recorded in the MOF’s CPPPC data set. Transport and environmental protection sectors networks are first described independently and then compared.

Measures of network size, interconnectedness and community structure were used to describe whole network characteristics. The network size was measured by the total number of nodes in each network. Average degree and network density indicate the interconnectedness of the network. Average degree means the average number of edges per node in the network (Barabási, 2016). Network density is the proportion of observed to potential network edges. A high average degree and network density are indications of structural cohesion (De Nooy et al., 2018). Average degree is robust to size differences, but a comparison of density measures for networks of different sizes is problematic. To investigate the community structure of a network, modularity was adopted. Modularity of a network is a measure of the cohesion of clusters within the network relative to the connections between clusters (Newman, 2006). A highly modular network has clusters that are disconnected from each other, while a network with lower modularity has more connections between clusters in the network.

To measure the influence and control power of CSOE s in PPP networks eigenvector centrality and betweenness centrality were used, respectively. Eigenvector centrality and normalized betweenness centrality were calculated using the free software Gephi (Bastian et al., 2009). The k-core decomposition measuring CSOE s’ central position in PPP networks was also computed as a robustness check. Furthermore, Wilcoxon rank-sum significance tests (adopted as the distribution of network centrality indicators is not normal invalidating parametric t-tests) were used to examine the differences in CSOE s’ dominance across sectors as well as over time.

The PPP networks are visualized abstractly in Figure 3 and geographically in Figure 4. Governments and societal capital organizations in the networks are geocoded based on their geographical locations and addresses in each city. For all subsidiaries of a societal capital organization, own addresses rather than those of their parent corporations were used.

NETWORK ANALYSIS RESULTS

Characteristics of PPP networks across sectors

PPP transport networks were larger and more cohesive than environmental protection networks. Table 1 compares the major network measures for these two groups of PPP networks. Compared with the network of environmental protection sector, transport PPP networks involved nearly 300 more actors and thus had far more PPP transactions during 2012–17. Specifically, in the transport sector, 479 city governments and 630 societal capital organizations participated in a total number of 2130 pair-wise PPP transactions. In the environmental protection sector, there were 338 city governments and 458 societal capital partners, which together entered into 1250 PPP contracts in total. However, it should be noted that many governments and organizations were present and overlap both networks. On average, there were nearly three societal capital organizations per PPP contract in both sectors. A network with a high average degree and network density is an indication of structural cohesion. Transport PPP network had a higher average degree, which suggests that a participant in the transport sector realized more PPP transactions on average than one in the environmental protection sector. The density of an environmental protection PPP network was a little higher than that in the transport sector. However, network density is sensitive to differences in network size, with density decreasing as more nodes are added. Therefore, the transport PPP network was more cohesive than the environmental protection network. Compared with its
counterpart, the transport PPP network had a lower modularity value, as shown in Table 1. This suggests that the transport PPP network was less partitioned into communities of densely connected nodes and hence was more interconnected and cohesive.

Figure 3 provides a visualization of these two PPP networks, and shows that transport PPP network incorporated more actors (city governments and societal capital organizations in total)
and more transactions than environmental protection network. Furthermore, the transport PPP network formed a large densely connected community, while the communities in the environmental protection network were more partitioned. Network visualization supports the results presented in Table 1, namely that the transport PPP network was larger in size and more cohesive than environmental protection sector network.

Figure 4. Distribution of public–private partnership (PPP) transactions in the transport and environmental protection sectors across China, 2012–17.
Source: National PPP database, China’s Ministry of Finance
Table 1. Comparative analysis of public–private partnership (PPP) networks of transport and environmental protection, 2012–17

|                      | Transport | Environmental protection |
|----------------------|-----------|--------------------------|
| Nodes                | 1129      | 827                      |
| Edges                | 2130      | 1250                     |
| Average degree       | 3.773     | 3.023                    |
| Network density      | 0.003     | 0.004                    |
| Modularity           | 0.812     | 0.915                    |

The traditional SNA visualization shown in Figure 3 was supplemented by the use of GIS tools to demonstrate specific geographical locations and patterns of all actors in PPP networks. Each actor in the transport and environmental protection PPP networks had a specific geographical location (city), but traditional SNA visualization randomly assigns network actors and is unable to show their spatial distribution. Given that regional disparity, regional economic complexity (Gao & Zhou, 2018) and differential urbanization (Chen et al., 2014) are significant features of China’s economy, spatial analysis of PPPs is of added value. Figure 4 plots the provincial distribution of PPP transactions in the transport and environmental protection sectors respectively in the period of 2012–17. The linkage weights (i.e., width) correspond to the number of PPP transactions between a local government and a societal capital partner based on their geographical locations. The PPP networks in these two sectors present similar spatial patterns. Provinces located along the coast tend to have more PPP transactions in both the transport and environmental protection sectors, while provinces located in south-west and north-west of China had relatively more transactions in the transport sector. The results also suggest that municipalities in provinces with a lower level of per capita CSOEs endowment tend to go beyond provincial boundaries to collaborate with CSOEs, reflecting their desire draws on CSOEs’ unique assets through their participation in PPP projects.

CSOEs’ dominance in PPP networks across sectors
CSOEs play a relatively dominant role in PPP networks of both transport and environmental protection sectors. Figure 5(a) reports the influence of different types of actors as measured by eigenvector centrality which measures the degree to which an actor in the network is allied with other well-connected actors. As shown, CSOEs are more influential actors in these two networks than local government participants, other SOEs and private firms. This suggests that CSOEs in both two sectors are dominant and exert an influence over other participants. CSOEs’ eigenvector centrality in the transport sector is twice as large as that in the environmental protection sector, indicating in accordance with the first sub-hypothesis that CSOEs are more dominant and influential in the property-based transport sector than in the knowledge-based environmental protection sector.

Similarly, as shown in Figure 5(b), CSOEs exercise much more control power than other types of participants in both sectors. Betweenness centrality was used to measure the network control power of actors. Betweenness centrality denotes the number of times an actor resides on the shortest path between other actors. As indicated, CSOEs’ betweenness centrality was lower in the environmental protection than in the transport sector, suggesting less control power over the former network.
A Wilcoxon rank-sum test showed that the mean influence and control power of CSOEs in these two sectors were significantly different. Therefore, the first sub-hypothesis pertaining to cross-sectoral variations in CSOEs’ influence and control power is supported.

**CSOEs’ dominance in PPP networks over time**

The dominant role of CSOEs varied between 2015 and 2017 in both the transport and environmental protection sectors (Figure 6) (for the mean comparison statistics, see also Table A1 in Appendix A in the supplemental data online). In the transport sector, CSOEs were the
most influential actor and their influence as measured by eigenvector centrality that increased steadily from 2015 to 2017. However, in the environmental protection sector, CSOEs’ influence initially decreased and then rose significantly in 2017. The increases of CSOEs’ influence in 2017 in both sectors is suggestive of the existence of a learning process for governments as they search, screen and match resources based on their demands and needs. Ongoing collaborations and observations of PPP transactions may strengthen CSOEs’ competitive advantages and their dominant positions.

Figure 7 shows that CSOEs’ control power increased in both sectors in the 2015–17 period (for the mean comparison statistics, see Table A2 in Appendix A in the supplemental data online). CSOEs have played an important brokerage role in both sectors, bridging various actors’ information-sharing and exchange networks. CSOEs’ betweenness centralities in both sectors rose steadily in 2015–17 and were higher than those for other PPP network participants, suggesting dominant CSOEs’ control power in brokerage and bridging. Accordingly, the second sub-hypothesis pertaining to variations in CSOEs’ dominant influence and control power over time in both sectors is supported.
As a robustness check, the $k$-core decomposition was included to measure CSOEs’ dominance in PPP networks across sectors and over time. The $k$-core decomposition assesses the influence of a node by using coreness as an indicator of whether a node is located in the core part of the network (Lü et al., 2016). Table 2 reports the results of the Wilcoxon rank-sum test based on the coreness of different types of PPP participants in the two networks. CSOEs’ coreness was higher in the transport than in the environmental protection sector. The difference between these two sectors was statistically significant. Moreover, as shown in Table 3, CSOEs’ coreness became statistically different from other types of PPP participants in both sectors in 2017. These robustness check results are highly consistent with those based on eigenvector and betweenness centrality.

**CSOEs’ dominance in PPP networks across geography**

The spatial distribution of CSOEs’ dominance was also explored. Figure 8 identifies the median centres of CSOEs’ influence and control power in the two sectors from 2015 to 2017. Median centre is a spatial statistic recoding the central tendency of geographically distributed values. CSOEs’ average eigenvector centrality and betweenness centrality by provinces in the
two sectors are reported in Figure 8 and were compared with the median centre (number of CSOEs per capita in each province) of eight major CSOEs and all their subsidiaries across Chinese provinces (a total of 356 firms).³

Figure 8 shows that the median centres of CSOEs’ transport sector eigenvector centrality in 2015–17 were closer to the median centre of provincial endowment of CSOEs than in the case of the environmental protection sector. Similarly, the median centres of CSOEs’ transport
sector betweenness centrality in the three years were closer to the median centre than in the environmental protection case. It suggests that the spatial distribution of CSOEs’ dominance in the transport sector more closely parallels or is restricted by the spatial distribution of major CSOEs across China’s provinces. On the contrary, although environmental sector PPP networks are dominated by CSOEs, the geographical distribution of participants was less

Figure 8. Central tendency of influence and control power of central/national government state-owned enterprises (CSOEs) in transport and environmental protection public–private partnership (PPP) networks versus major CSOEs in China, 2015–17. Source: National PPP database, China’s Ministry of Finance
dominated by the geographical distribution of CSOEs, perhaps facilitating collaboration with non-CSOEs actors. These results confirm the third sub-hypothesis pertaining to geographical variations in CSOEs’ influence and control power. Because of a high dependence on CSOEs in the transport sector, the geography of network participants was closely aligned with the provincial distribution of CSOEs.

CONCLUSIONS AND POLICY IMPLICATIONS

Informed by the RBV and RDT, this research examined whether CSOEs would exert influence and control over other participants in PPP networks. An SNA of transport and environmental protection sectors PPP projects in 2012–17 showed that the transport sector PPP network was larger and more cohesive than that of the environmental protection sector, and that the influence and control power of CSOEs was greater in the former. This result corresponds with the RBV’s suggestion that transport PPPs rely and depend more than environmental protection PPPs on resources and assets possessed by CSOEs, such as credentials, financial and human capital, while a greater dependence on CSOEs in transport suggests in the light of the RDT that CSOEs’ control power in this sector is greater than in the environmental protection sector.

CSOEs’ influence and control power have increased since 2017 in both sectors. Because of a sudden surge in the number and value of PPP projects, in 2017 China’s central government tightened PPP qualifications and approval requirements, possibly further strengthening CSOEs’ network influence and control power as a result of their competitive advantages over sub-national SOEs and private firms in terms of financial capacity, expertise, human capital and credibility.

Geographically the spatial concetration of CSOEs’ influence and control power in the transport sector is more aligned with the geographical distribution of Chinese CSOEs than in the environmental protection sector where CSOEs’ dominance is somewhat less. Closer alignment in the former than the latter may suggest local governments in the environmental protection sector have greater flexibility and discretion and can seek non-CSOEs participants with strategic access to key technology and skills.

CSOEs’ dominant role in PPP networks in both transport and environmental protection sectors are indicative of their superior possession of strategic assets. Policy-makers should reduce resource gaps between SOEs and private businesses, and only in so doing it is likely that the relative importance of CSOEs will be reduced, and the presence and involvement of non-SOE in China’s PPPs can be enhanced.

The significance of this research is that it provides an analytical framework to identify the differing roles and different degrees of access and control over resources of different actors in Chinese PPP networks by drawing on SNA to examine governance networks. In this way, PPP projects and collaborations are not isolated or independent from each other. From a network perspective, the interactions among different types of participants are better discerned.

Several limitations remain to be addressed in future research. First, one must take care not to generalize from just the transport and environmental protection sectors. Second, attention should be paid to the distinctive characteristics of different local governments.

NOTES

1. The use of both population-scale network data and social network analysis in this paper may contribute to the emerging field of ‘computational socioeconomics’. For details on computational socioeconomics, see the review paper by Gao et al. (2019).
2. As the total number of PPP projects before 2015 is almost negligible, we only explore here the trend over the period of 2015–17.
3. There are 21 CSOEs participating in PPP projects in the transport and environmental protection sectors. Subsidiaries of CSOEs are included as separate enterprises. In total, there are 175 CSOEs and their subsidiaries acting as societal capital organizations in the two sectors. Eight major CSOEs are selected as more than three of their subsidiaries participate in PPP projects. The proportion of subsidiaries participating in PPPs from those eight CSOEs is near 85%.

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