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Research Article

An Urban Network Study of Government Procurement Activities: A Case Study of Northeast China

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Urban networks have been widely examined using infrastructure connection and firm connection data. In particular, urban networks constructed based on firm connection data have been used to depict the circulation of capital, information, personnel, and products between cities. Existing studies on firm connection networks rely on either inter- or intrafirm relationships. However, there exist various important extra-firm relationships, such as those between firms and governments, research institutions, and nonprofit organizations. This study innovatively incorporates the extra-firm relationships between governments and firms into urban network construction to provide new insights into the field of urban network research. Using Northeast China as a case study, we construct government procurement activity (GPA) connection networks for both central projects and local projects at the regional and national scales. Social network analysis and regression analysis are used to analyze the network characteristics and factors associated with the network structure. The results show that three provincial capitals (Harbin, Changchun, and Shenyang) hold dominant positions across all the networks. While these capitals serve as GPA suppliers in the region, they are mainly GPA consumers nationally. The factors of spatial proximity, economic development, population, and provincial boundaries were found to be significantly associated with GPA connections. Our study provides important insights into the role of cities in firm-government supply-demand networks. This research can be used to help formulate effective strategies to improve a city's competitiveness and cities' cooperation in the GPA supply-demand network.

1. Introduction

"Space of flows," introduced by Castells [1] to characterize social practices through flows, differs substantially from "space of places" that focuses on the traditional physical world of neighborhoods and local business nodes [2]. Castells (1996) highlighted that cities in the information age are the main nodes and hubs of the "space of flows" [1]. High-speed transportation and communication networks have greatly facilitated the flows of people, goods, capital, and information between cities. Due to the importance of these flows, research on urban networks has received increasing attention in recent years [3, 4], and the role of cities is being increasingly determined by how they are connected with other cities. The complex connections between places in urban networks have made current regional spatial structures deviate significantly from the systematic, hierarchical pattern described in the "Central Place Theory".

Scholars have used a wealth of connection data to characterize urban networks. In these studies, urban networks have been mainly studied using infrastructure connection and firm connection data. While transportation and communication network data relating to the operations that occur between cities, such as aviation [5–7], railway [8, 9], highway [10], telecommunication [11], and the Internet [12] data, have been used to examine intercity infrastructure connections, the organizational and economic activity relationships of firms have been used to depict the circulation of capital, information, personnel, and products between cities. In addition to infrastructure and firm connection data, the advent of the big data era has made more movement data available, such as data on the movement of people, information, and knowledge [13–16]. Urban networks constructed based on these data provide new insights into the complexity of cities.

Urban networks constructed using firm connection data have mainly focused on intrafirm and interfirm relationships. While intrafirm connection networks focus on the geographical distributions of the enterprise's headquarters and branches [17–21], interfirm connection networks take into account the cooperation relationships between firms [22–24]. Despite the importance of inter- and intrafirm relationships, in economic and social activities, there are various important extra-firm relationships [25], including those between firms and many other entities, such as governments, research institutions, nonprofit organizations, nongovernmental organizations, and market consumers. These relationships can have a significant impact on firms' operations and the overall economic development. However, because the relevant data are often challenging to collect, and the associated extra-firm relationships are difficult to quantify, there has been little research incorporating extra-firm relationships into urban network studies.

Extra-firm relationships can be identified through product distribution relationships, such as service and consumption relationships [26–28]. Consumption relationships are especially enlightening for urban networks studies [29]. The government is often the largest consumer in a country [30], as it needs to purchase goods and services from domestic and foreign firms for government departments and affiliated groups to perform its daily state activities and offer services to the general public [31]. These purchasing activities are known as Government Procurement Activities (GPAs). As an important part of the consumer market, GPAs have a large impact on the economy. Changing the procurement magnitude or structure can greatly affect social and economic development, industrial structure, and the public living environment [32].

Despite the importance of the extra-firm relationships between governments (purchasers/demanders) and firms (suppliers), there has been little research incorporating such relationships into urban network studies. The current study intends to fill this research gap. Specifically, We focus on China, where the supply-demand relationship between firms and government is especially important. Through large scale planned procurement activities, China's national and local governments not only perform their daily affairs, but can also help promote equity by subsidizing poor areas or disadvantaged groups through targeted projects [33]. In Northeast China, due to the area's lack of innovation and market vitality, it is very important for the government to perform procurement activities to improve the economic development of the region [34]. Incorporating GPA supply-demand relationships into urban network construction will help identify the role of cities and city dyads with regard to the extra-firm connections between governments and firms in this region. Such an analysis will provide insights into the efforts to strengthen the GPA connections and help enhance the competitiveness of cities in Northeast China. Thus, this paper aims to construct and analyze GPA connection-based urban networks for Northeastern China. The specific research questions include the following: 1. How can we construct a GPA supply-demand urban network? 2. What are the characteristics of the GPA connection networks in Northeast China? 3. What factors are associated with the spatial structures of the GPA connection networks in Northeast China?

The remainder of this paper is organized as follows: Section 2 introduces the study area, data sources, and research methods. Section 3 analyzes the GPA connection networks at the regional and national scales and identifies factors associated with the network structure. In Section 4, we provide some discussion on the analysis results and policy implications, and Section 5 concludes the research.

2. Materials and Methods

2.1. Study Area. We conducted our study in Northeast China, as shown in Figure 1. This region includes the provinces of Heilongjiang, Jilin, and Liaoning, with 36 prefecture and subprovincial level cities. Harbin, Changchun, and Shenyang are the capital cities of Heilongjiang, Jilin, and Liaoning, respectively. These three capital cities, along with Dalian, are the four subprovincial cities in Northeast China [35], serving as the economic and social centers of the region. This region covers a total land area of 787,300 km^2, with an overall population of 108.36 million. The region had a GDP of 5,675.159 billion yuan (about 857.61 billion dollars) in 2018, which accounted for 6.30% of China's overall GDP (China Statistical Yearbook 2018). As the historical industrial foundation of China, Northeast China has been faced with multiple social and economic development challenges in recent years. State-owned firms play a dominant role in the region, but their operational efficiency is low. With the slow development of small- and medium-sized private firms, innovation and market vitality in the region are lacking [34]. It is, therefore, important for the government to perform procurement activities to help improve the economic development of Northeast China. Currently, the role of GPAs is significant in Northeast China, which makes the study area a suitable site to explore the GPA connections among cities.

2.2. Data Sources. Thanks to a regulation mandating the comprehensive disclosure of GPA transaction records [36], we obtained 446,877 GPA transaction records for 2018 from the Chinese government procurement website. Each record contains information on the project name, purchaser name, purchaser address, supplier name, supplier address, and transaction amount. Depending on the budgetary sources, a project is defined as either a central project or local project. With funding sources from national financial expenditures, central projects generally focus on economic development and people's livelihoods at the regional/national scale and also tend to have large budgets and high technical requirements. In contrast, local projects are relatively smaller projects funded by local governments with lower technical requirements [33].

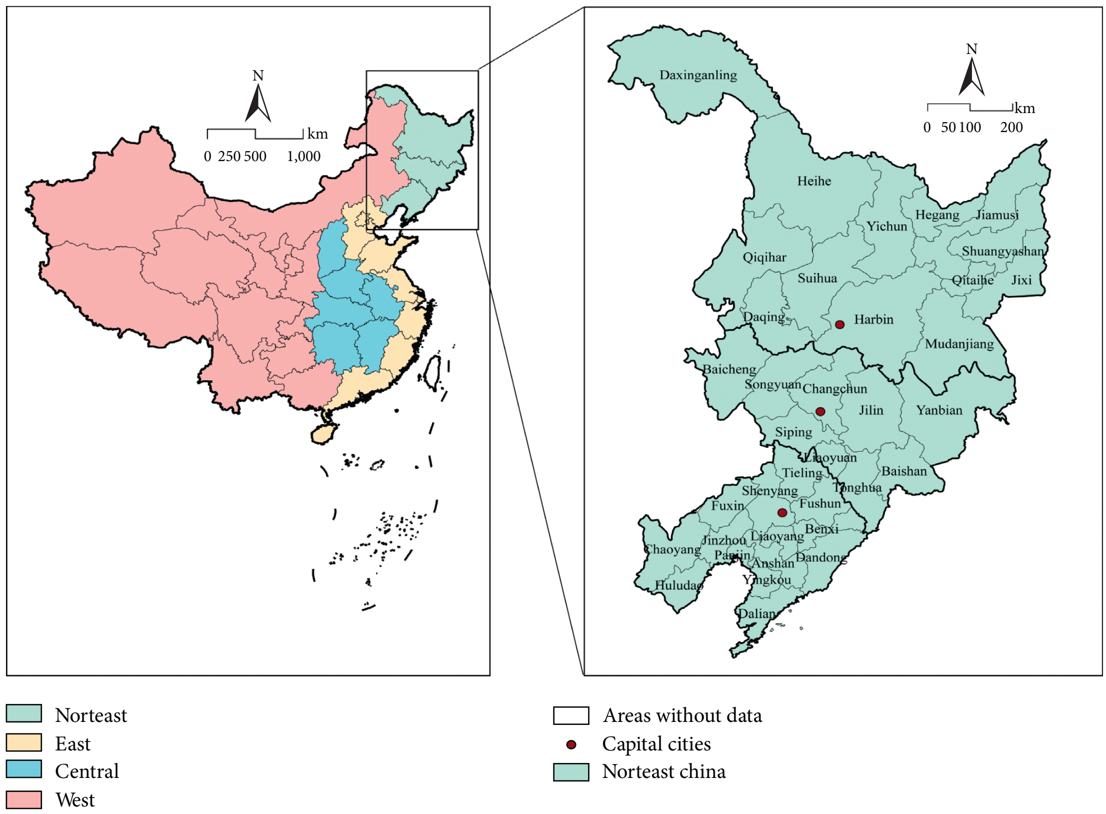

Figure 1: Map of the study area.

Among the 446,877 GPA transactions, we extracted 1,251 and 45,319 transaction records related to Northeast China for the central projects and local projects, respectively. Table 1 provides a summary of the data extracted. These records contain 1,523 and 59,218 GPA supply-demand connections for central projects and local projects, respectively. Excluding all connections within the same city provides 945 and 23,774 intercity connections for the central projects and local projects, respectively. These intercity connections are grouped into connections within Northeast China and those between Northeast China and other regions in the country.

We also collected socioeconomic data to examine the factors associated with the GPA connection network structure. These data include the Gross Domestic Product (GDP) and population of cities. These data were collected from the Statistical Yearbook of China's Cities and the Statistical Yearbook of the Province.

2.3. Methods

2.3.1. Construction of Urban Networks

(1) Schematic GPA supply-demand connections between governments and firms. Figure 2 gives a simple illustration of the GPA supply-demand connections among five cities with three cities (cities 1 to 3) belonging to the same region. In China, firms in a particular city can be the GPA suppliers of government (s) in cities of the same region (e.g., Northeast China) or in different regions. Although firms can participate in GPA bidding activities nationwide, due to a variety of reasons, such as regional specialization, geographical proximity, administrative boundaries, or the technical requirements of projects, cities may differ substantially in their GPA connections. For example, firms in a city might be more likely to participate in local projects with governments in the same region than with those outside the region, while such a pattern may not be as obvious for central projects. As illustrated in Figure 2, the firms in city 1 have GPA connections with governments in the same region for both local projects (cities 1, 2, and 3) and central projects (city 3) and only have GPA connections with governments outside the region (city 4) for central projects. Thicker lines represent stronger GPA connections. In this case, for local projects, city 1 has stronger GPA connections with city 2 than with city 3 due to spatial proximity.

(2) Construction of directed-weighted networks. To construct the GPA connection networks, we treated prefecture and higher-level cities as nodes. Directed linkages were constructed between a pair of nodes based on whether there existed a GPA connection between the two cities. For example, if a firm in city i was identified as a GPA supplier for the government in city j, we constructed a directed linkage from node i to node j. We also attached a weight to each linkage to reflect the amount of GPA connections between two cities. Given a total of N cities, we could then construct a matrix to represent the intercity GPA connections (formula (1)). In (1), r_{ij}

Table 1: Summary statistics of the GPA supply-demand connections.

Project type	Number of records	Supply-demand connections	Intracity supply-demand connections	Intercity supply-demand connections		
				Within Northeast	Between Northeast China and other regions	Sum
Central projects	1251	1523	578	217	728	945
Local projects	45319	59218	35444	12252	11522	23774

Note: A GPA record may include more than one supplier, so the number of GPA connections is greater than the number of transaction records.

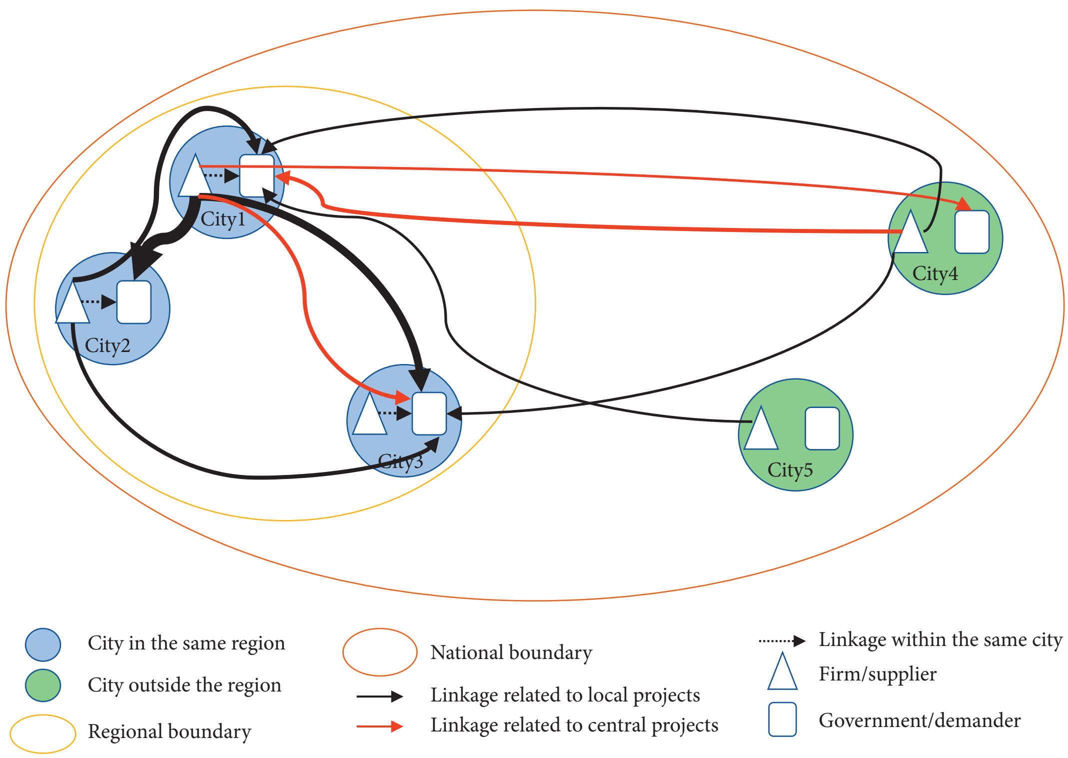

Figure 2: Schematic government procurement activity (GPA) connections.

represents the cumulative number of GPA connections from firms in city i (supply city) to the government in city j (demand city).

$$R = \begin{bmatrix} 0 & r_{12} & \cdots & r_{1(n-1)} & r_{1n} \\ r_{21} & 0 & \cdots & r_{2(n-1)} & r_{2n} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ r_{(n-1)1} & r_{(n-1)2} & \cdots & 0 & r_{(n-1)n} \\ r_{n1} & r_{n2} & \cdots & r_{n(n-1)} & 0 \end{bmatrix}. \quad (1)$$

For the purpose of this study, we constructed urban networks at two scales: the regional scale and the national scale. At the regional scale, networks were constructed based on the GPA supply-demand connections within Northeast China; at the national scale, networks were constructed using the GPA connections between cities in Northeast China and those outside the region. At each scale, two networks were established based on the two types of projects: local projects and central projects. Table 2 provides a summary of the four networks constructed.

2.3.2. Social Network Analysis

(1) Centrality. In this study, an important task is identifying the key nodes in the GPA supply-demand networks. Specifically, we used centrality to evaluate the importance of cities in the four urban networks constructed. Centrality can be evaluated using degree centrality, betweenness centrality, and closeness centrality [37]. Degree centrality computes a node's importance by counting its number of direct connections with other nodes in the network. Betweenness centrality describes the importance of a node by measuring the number of paths that pass through the node. Closeness centrality is used to examine how "close" the node is to, or how quickly it can communicate with, other nodes in the network. Given that the GPA supply-demand networks constructed in this study do not involve intermediate nodes or navigation paths, degree centrality is more appropriate for measuring node importance. As our networks are directional, both indegree and outdegree centrality are considered. In particular, the indegree centrality of a city refers to the number of GPA connections that the governments in the

Table 2: The four GPA-based urban networks.

Scale	Urban network constructed	Number of nodes	Number of linkages
Regional scale	Regional network for central projects	24	47
	Regional network for local projects	36	589
National scale	National network for central projects	79	163
	National network for local projects	304	2337

city have with firms in other cities, and the outdegree centrality of a city refers to the number of GPA connections that the firms in the city have with governments in other cities. We can then compute the net outdegree as the outdegree centrality subtracted by the indegree centrality. Table 3 lists all the centrality metrics used in this study.

(2) Cohesive Subgroup. In addition to identifying the key nodes, another important aspect of social network analysis concerns the network substructure [37]. To analyze the substructure of the GPA connection networks, we focused on detecting the cohesive subgroups. Cohesive subgroups refer to network subclusters that are more homogeneous based on similarities or diffusion among nodes. Important metrics used to measure subgroup homogeneity include reciprocity, closeness or reachability, frequency, and relative density [37]. For this research, we evaluated reciprocity based on intercity GPA connections. In particular, we focused on the amount of GPA connections and did not differentiate supply cities from demand cities. The reciprocity evaluation led to an undirected network. In particular, we calculated the average GPA connections in a network and used that value as a threshold to construct a new connection network, as follows: if the GPA connection of a linkage is larger than the threshold, the linkage was kept in the new network; otherwise, the linkage was removed. Based on the new network, we then used the Cliques method in UCINET to identify cohesive subgroups. Since the national networks only involve connections between cities in Northeast China and those outside the region, and connections between cities outside Northeast China are missing, as it is not meaningful to study the cohesive subgroups in national networks, therefore, this paper only analyzes the cohesive subgroup structures of the regional networks.

2.3.3. Regression Analysis of Factors Associated with the Network Structure. We further examined a range of factors associated with the GPA connection network structure. Research on existing urban networks shows that demographic status, economic development, administrative boundaries, and geographical distance can affect the interactions between cities [38–40]. In the constructed GPA connection networks, we conducted a regression analysis to examine the association of GPA connections with spatial proximity, economic development, population, and administrative boundaries. The associated variables are provided in Table 4.

Similar to many interaction studies [41, 42], we adopted a natural logarithm of the dependent variable; the regression model is as follows:

$$\ln \text{Conn} = \alpha_0 + \beta_1 \text{Distance} + \beta_2 \text{Spop} + \beta_3 \text{Dpop} + \beta_4 \text{Sgdp} + \beta_5 \text{Dgdp} + \beta_6 \text{Inpro}, \quad (2)$$

where α_0 and β are the parameters to be estimated. For each of the four urban networks constructed, we conducted a regression analysis to analyze the factors associated with the GPA supply-demand connections.

3. Results

3.1. Urban Networks within Northeast China

3.1.1. Spatial Connection Pattern. Figure 3 shows the spatial patterns of the regional urban networks constructed based on the GPA connections for both central projects and local projects. The regional network for central projects is rather sparse, with a major concentration in the Harbin–Changchun–Shenyang–Dalian corridor (Figure 3(a)). In particular, the linkage from Harbin to Changchun has the largest GPA connections (34) in the network. In each province, there are multiple linkages between the capital city and other cities in the same province, further highlighting the key role of capital cities in the network.

The regional network for local projects mainly presents a localized hub-and-spoke pattern in each province, with the capital city serving as the hub connecting multiple cities in the same province (Figure 3(b)). Based on the connection directions, the firms in capital cities are mainly GAP suppliers, whereas the governments of other cities are mainly GPA demanders. The provincial boundary appears to play a critical role, as the GPA connections between cities from different provinces are relatively weak. In total, there are 1,562 interprovincial connections, which is much less than the number of intraprovincial connections (10,690). Meanwhile, compared to the regional network for the central projects in Figure 3(a), the regional network for local projects in Figure 3(b) is much denser, with significantly more nodes and linkages.

3.1.2. Centrality of Cities. Table 5 lists the top 10 cities with the highest degree centrality for the two regional networks. According to Table 5, the three capital cities

Table 3: Centrality metrics used to measure the importance of nodes in the GPA connection networks.

Indicator	Formula	Interpretation of formula	Topological meanings
Degree centrality	$C_D(i) = \sum_{j=1}^{N} r_{ij} + r_{ji}$	Sum of all arcs directly connected to node i	Amount of GPA connections that city i has with other cities, reflecting the cumulative times of city i participating in the GPA network
Outdegree	$C_{OD}(i) = \sum_{j=1}^{N} r_{ij}$	Sum of all arcs originating from node i	Amount of GPA connections firms in city i has with governments in other cities, reflecting the cumulative times of city i as suppliers in GPA network
Indegree	$C_{ID}(i) = \sum_{j=1}^{N} r_{ji}$	Sum of all arcs ending at node i	Amount of GPA connections government in city i has with firms in other cities, reflecting the cumulative times of city i as purchasers in GPA network
Net outdegree	$C_N(i) = C_{OD}(i) - C_{ID}(i)$	The difference between the outdegree and indegree of node i	The difference between the amount GPA connection outflows and inflows. If $C_N(i) > 0$, city i mainly plays the role of "service provider" in GPA network; otherwise, "consumer"

Note: N is the total number of nodes in the network.

Table 4: Variables examined in the regression analysis.

Type of variables	Name	Symbol	Interpretation
Dependent variable	GPA connection	Conn	The number of GPA connections between supply city and demand city
Independent variables	Geographical distance	Distance	The geographical distance (km) between a pair of cities
	Supply population	Spop	Population of GPA supply city (10^4 persons)
	Demand population	Dpop	Population of GPA demand city (10^4 persons)
	Supply GDP	Sgdp	Gross domestic product of supply city (10^{10} Yuan),
	Demand GDP	Dgdp	Gross domestic product of demand city (10^{10} Yuan)
	Within the same province	Inpro	Dummy variable: 1, if two cities are in the same province and 0 otherwise. This variable is only included in the analysis of the regional network

(Harbin, Changchun, and Shenyang) in Northeast China play the most important role in the GPA supply-demand networks, with a degree centrality far greater than that of other cities in the region. Comparing the indegree and outdegree centrality of the top 10 cities shows that, except for the three capital cities, the outdegrees of all cities are less than their indegrees, resulting in negative net outdegrees. This indicates that the region capital cities mainly play the role of "service provider," while the other cities are mostly "consumers." This is also consistent with what we found in Figure 3. In addition, although two major cities, Jilin and Dalian, rival the capital cities of Jilin and Liaoning in terms of their economic and social development, respectively, and are also among the top 10 with the highest degree centrality, their negative outdegrees suggest their "consumer" role in the network.

While the key roles of the capital cities and the two major cities of Jilin and Dalian are consistent with the cities identified by studies focused on technology, transportation, information, and intrafirm networks [40, 43, 44], the GPA connection network analysis indicates a few important cities that are different from those presented previous studies. For example, the poor and undeveloped cities in Northeast China, including Yanbian, Baicheng, and Baishan, are marginalized in the transportation, information, and innovation networks, but their degree centrality is high in the GPA connection networks. This is because, since the implementation of the China's Targeted Poverty Alleviation policy, these poverty-stricken counties have received substantial amounts of funding from national and local governments [45] to facilitate their local economic development. The large volume of projects has made these areas important nodes in the GPA connection networks.

3.1.3. Analysis of Cohesive Subgroups. Table 6 shows the cohesive subgroups identified for the regional networks. For the network for local projects, there are twelve cohesive subgroups, including two 5-city subgroups, four 4-city subgroups, and six 3-city subgroups. Most subgroups contain one capital city, with other cities from the same province as the capital city. For example, in the 4-city subgroup {Changchun, Jilin, Liaoyuan, Siping}, Changchun is the capital city of Jilin province, and the cities of Jilin, Liaoyuan, and Siping are all in Jilin province. There are three subgroups that contain cities (mainly capital cities) from multiple provinces. For example, the 4-city subgroup {Harbin, Changchun, Shenyang, Jilin} contains three provincial capitals. Several cities can be found in multiple subgroups, indicating their important role in the network. These cities are mainly capital cities. In terms of the network for central projects, due to the small number of city nodes and linkages in the network, only two 3-city subgroups are found. Both subgroups contain cities from multiple provinces, and the majority of these cities are provincial capitals.

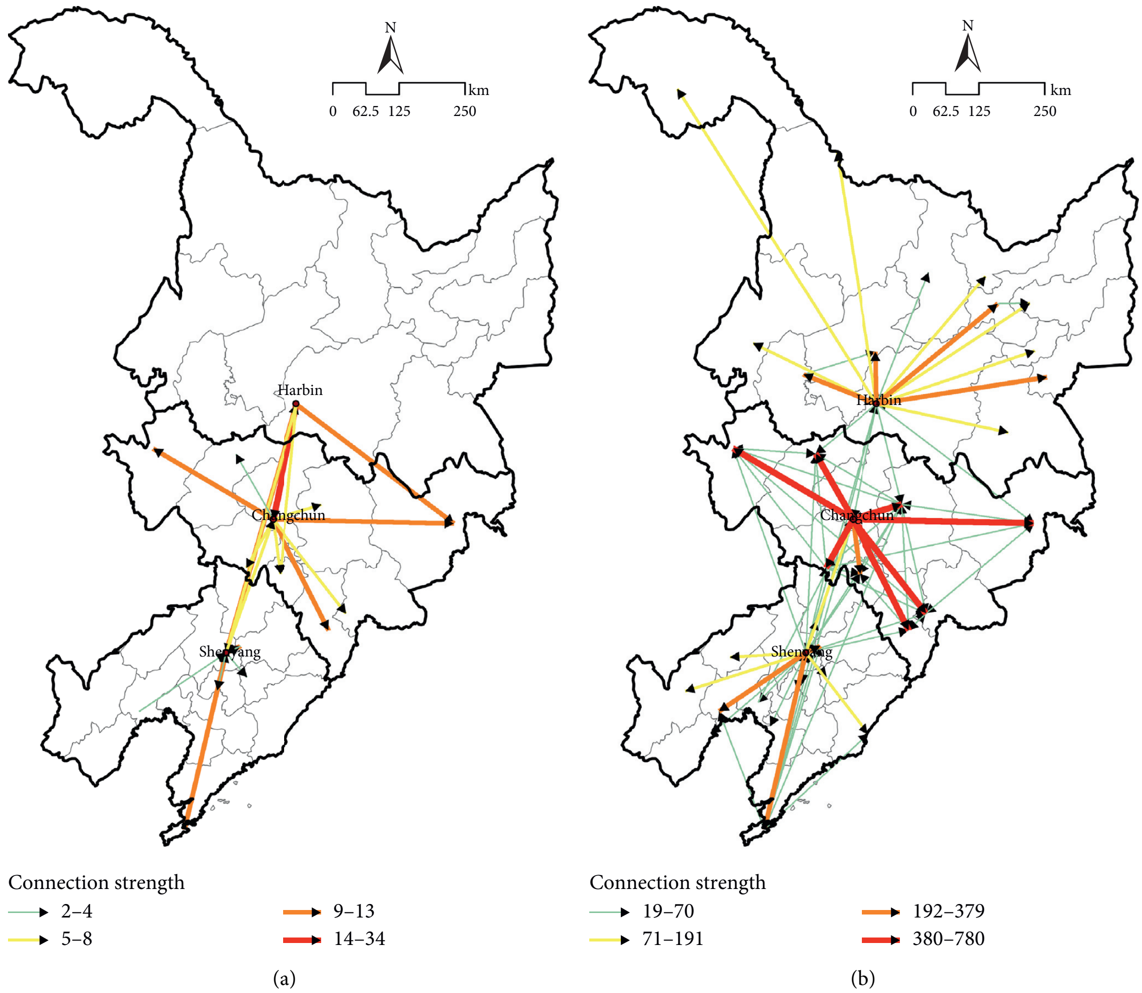

FIGURE 3: Spatial connection pattern of regional networks. (a) Central projects. (b) Local projects.

3.2. Urban Networks between Northeast China and Other Regions in China

3.2.1. Spatial Connection Patterns. Figure 4 presents the GPA connection pattern at the national scale. In total, there are 79 nodes and 163 linkages. As shown in Figure 4(a), the national network for central projects is mainly concentrated in five cities. Among these five cities, Beijing is the only one outside the region, while the other four are subprovincial cities in Northeast China. The bidirectional linkages also indicate that Beijing is not only an important GPA supplier, but also a major GPA consumer of the cities in Northeast China.

Compared with the network for central projects, the network for local projects shown in Figure 4(b) shows a notably different spatial pattern. There are significantly more nodes (304) and linkages (2337) in the network for local projects. For local projects, Northeast China appears to have a substantial amount of connections with cities in the eastern coastal provinces, as well as a few cities in central and western China. Considering the GPA connection directions, linkages from cities outside Northeast China to cities within this region tend to have higher GPA connections compared to linkages from cities in the region to cities outside the region.

3.2.2. Centrality of Cities. Table 7 lists the top ten (10) cities with the highest degree centrality for the two national networks. Among the ten cities, four and seven cities are located in Northeast China for the networks for central projects and local projects, respectively. For both networks, the cities of Shenyang, Changchun, Harbin, and Dalian in the region and Beijing and Shanghai outside the region are among those with the highest degree centrality. In general, the outdegrees of cities within Northeast China are less than their indegrees, resulting in negative net outdegrees. In contrast, the outdegrees of cities outside the region (e.g., Beijing, Shanghai) are generally greater than their indegrees, leading to positive net outdegrees. This suggests that cities in Northeast China mainly serve as "consumers" in the national GPA connection networks, while cities outside the region provide more technologies, products, and services to the region.

It is also worthwhile to note several different characteristics related to the centrality of cities in the two national GPA networks. First, Table 7 shows that cities with high overall degree centrality in the network for central projects mostly have both high indegrees and high outdegrees, whereas, in the network for local projects, most cities with

Table 5: Degree centrality of the top 10 cities in the regional networks.

Central projects					Local projects				
City	Degree centrality	Indegree	Outdegree	Net outdegree	City	Degree centrality	Indegree	Outdegree	Net outdegree
Changchun	116	47	69	22	Changchun	5022	892	4130	3238
Shenyang	84	31	53	22	Harbin	2846	454	2392	1938
Harbin	71	14	57	43	Shenyang	2496	306	2190	1884
Dalian	31	17	14	−3	Jilin	1541	1045	496	−549
Yanbian	23	22	1	−21	Baishan	964	877	87	−790
Fushun	15	12	3	−9	Dalian	953	550	403	−147
Baicheng	14	12	2	−10	Siping	890	558	332	−226
Liaoyuan	12	12	0	−12	Tonghua	855	680	175	−505
Jilin	10	8	2	−6	Songyuan	821	670	151	−519
Tonghua	10	10	0	−10	Baicheng	804	705	99	−606

Table 6: Cohesive subgroups in regional networks.

Project type	Cohesive subgroups
Central projects	3-city subgroups: {Harbin, Changchun, Shenyang}; {Harbin, Changchun, Yanbian}
Local projects	5-city subgroups: {Changchun, Shenyang, Baishan, Jilin, Tonghua}; {Changchun, Baicheng, Jilin, Siping, Songyuan} 4-city subgroups: {Harbin, Changchun, Shenyang, Jilin}; {Harbin, Changchun, Shenyang, Dalian}; {Changchun, Jilin, Liaoyuan, Siping}; {Changchun, Baishan, Jilin, Yanbian} 3-city subgroups: {Harbin, Changchun, Shenyang}; {Shenyang, Dalian, Dandong}; {Shenyang, Dalian, Fushun}; {Shenyang, Dalian, Jinzhou}; {Harbin, Daqing, Suihua}; {Harbin, Jiamusi, Shuangyashan}

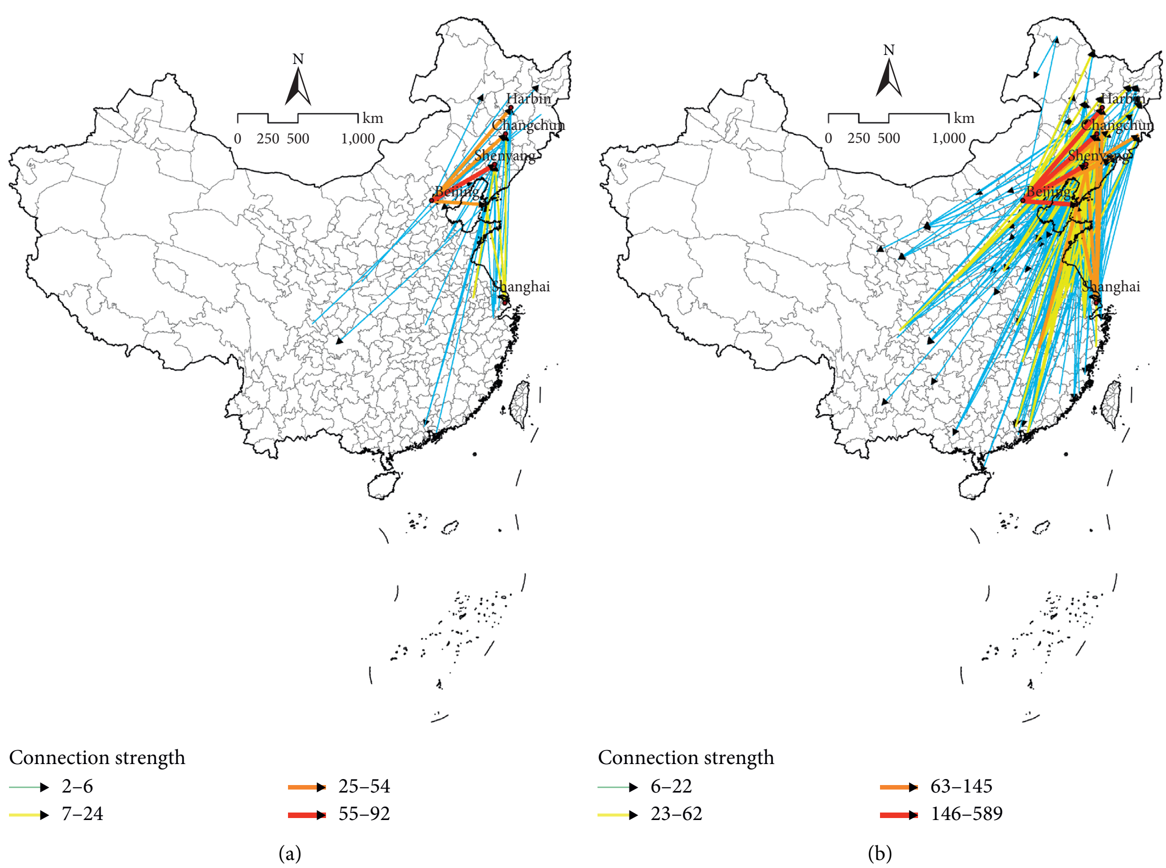

Figure 4: Spatial connection pattern of national networks. (a) Central projects. (b) Local projects.

Table 7: Degree centrality of the top 10 cities in the national networks.

Central projects					Local projects				
City	Degree centrality	Indegree	Outdegree	Net outdegree	City	Degree centrality	Indegree	Outdegree	Net outdegree
Beijing (O)	450	226	224	−2	Beijing (O)	3407	200	3207	3007
Shenyang (I)	270	153	117	−36	Changchun (I)	2065	1669	396	−1273
Changchun (I)	150	90	60	−30	Harbin (I)	1725	1392	333	−1059
Harbin (I)	134	86	48	−38	Shenyang (I)	1559	872	687	−185
Dalian (I)	117	73	44	−29	Dalian (I)	1559	1201	358	−843
Shanghai (O)	60	16	44	28	Shanghai (O)	631	17	614	597
Guangzhou (O)	25	11	14	3	Jilin (I)	482	461	21	−440
Nanjing (O)	20	3	17	14	Nanchang (O)	424	7	417	410
Tianjin (O)	18	11	7	−4	Yanbian (I)	347	345	2	−343
Hangzhou (O)	15	0	15	15	Jinzhou (I)	286	271	15	−256

Note: (I) represents a city within Northeast China; (O) represents a city outside Northeast China.

high overall degree centrality have either high indegrees or high outdegrees. This indicates that the key cities in the GPA networks for central projects play important roles as both suppliers and consumers, while key cities in the network for local projects are mainly either suppliers or consumers, but not both. For example, in the network for local projects, the cities of Harbin, Changchun, and Shenyang have significantly higher indegrees than their corresponding outdegrees. Second, the key cities outside Northeast China in the network for central projects are all located in the eastern coastal region, while, in the network for local projects, a few important cities are located in central China. For example, Nanchang city in central China plays a key role in the network for local projects, with a net outdegree slightly lower than that of Beijing and Shanghai. This is mainly attributed to Jinxian County, which is under the jurisdiction of Nanchang city. As the "first medical device county in China," Jinxian experiences annual sales of around 100 billion yuan and has an important share in the national medical device market. Firms in Nanchang serve as the primary suppliers for the medical device procurement of local hospitals in Northeast China, making Nanchang a critical node in the network.

3.3. Comparison of Regional and National Networks. Overall, there are both similarities and differences when comparing the structures of the regional and national networks. For similarities, the key cities of Northeast China identified at the two scales are generally the same. Capital cities such as Harbin, Changchun, and Shenyang have high degree centrality in both the regional and national networks. In addition, the networks for central projects at each of the two scales are significantly sparser than the corresponding networks for local projects.

Notably, there are differences when comparing the networks at the two scales. On one hand, despite the key role of the provincial capitals of Northeast China, their net outdegrees are positive in the regional networks but negative in the national networks. This suggests that these capital cities play the role of GPA supplier in the region but mainly play a consumer role on a national scale. On the other hand, a comparison of the networks at the two scales indicates that the within-region GPA connections are much stronger than the interregion GPA connections in the networks for local projects. The Wilcoxon signed-rank test shows that the medians for the indegrees and outdegrees of Northeast China's cities in the regional network for local projects are significantly larger than those in the national networks for local projects (p-values <0.01). However, the centrality difference is not significant for the two networks when central projects are considered.

3.4. Factors Associated with the GPA Supply-Demand Connections. The results of the regression analysis are shown in Table 8. The examined factors show a reasonable ability to explain the variation in the GPA connections for the four networks, with an adjusted R-square ranging from 25.6% to 51.7%. Overall, the model offers a better fit for the regional networks than the national networks. The variables of geographical proximity, population, GDP, and administrative boundaries are significant in one or more networks. We provide a detailed discussion of these variables in the following section.

In Table 8, geographical distance can be seen to be negatively associated with GPA connections in all the networks except for the regional network for central projects. This suggests that firms in a city are more likely to be the GPA suppliers of another city when the two cities are close in space. Closer spatial proximity helps save the transportation time and costs [39] needed for firms to participate in a government's on-site bidding and, therefore, helps firms fulfill the purchasers' requirements, as well as increasing the firm's probability of winning the bidding.

City population is positively associated with GPA connections in the two regional networks and the national network for local projects. In particular, the populations of supply cities were found to be significant in all three networks. That is, the greater the population of a city, the more

Table 8: Regression analysis results.

Model	GPA supply-demand urban networks			
	Regional networks		National networks	
	Central projects	Local projects	Central projects	Local projects
Distance	0.021	−0.182***	−0.189***	−0.071***
Spop	1.052***	0.368***	−0.068	0.107***
Dpop	0.064	0.055	0.145	0.139***
Sgdp	−0.212	0.232***	0.632***	0.416***
Dgdp	0.199	0.209***	0.249**	0.121***
Inpro	0.333	0.422***	—	—
Constant	−1.876*	−0.343*	−0.221	0.102
R-squared	0.431	0.522	0.340	0.258
Adjusted R-squared	0.346	0.517	0.319	0.256

Note: Only standardized coefficient estimates are included in the table. *, **, and *** indicate that the coefficient is significant at a 0.1, 0.05, and 0.01 levels, respectively.

GPA connections that city has with other cities. The demand city's population is only significant in the national network for local projects.

The GDP of supply cities and demand cities was found to be significant and positively associated with GPA connections in the two national networks and the regional network for local projects. This suggests that the higher the level of economic development of the two cities is, the more GPA connections there will be between them. This is reasonable, given that cities with a higher level of economic development often have larger budgets and may need to purchase more services/goods to support their normal operations. In addition, firms in cities with a higher GDP may be more diverse and competitive [46], resulting in more GPA outflows to other cities. The regression results suggest that the supply city's GDP plays a greater role than that of the demand city, highlighting the importance of supply cities.

The regression results further indicate that the administrative boundary, defined based on whether two cities are located in the same province, is only significant and positively associated with the GPA connections in the regional network for local projects. That is, cities within the same province tend to have more GPAs for local projects. Moreover, in this network, the administrative boundary is more important than all other factors examined. Given the division of markets by administrative boundaries, the varying procurement policies in different provinces, and the competition among provinces, each province will be more inclined to protect its local firms and purchase services or products from local firms for local projects. However, for central projects, which often have high technical requirements and heavy workloads, firms within the same province might not be able to meet the requirements of procurement.

4. Discussion

The previous analysis showed obvious differences in the characteristics between networks for central projects and local projects. Firstly, the numbers of nodes and linkages in the networks for local projects were found to be much larger those of the networks for central projects at both regional and national scales. This is reasonable since China's central budget expenditures only account for 35% of national financial expenditures, which is significantly lower than the local budget expenditures (65%) [47]. Central budgets are usually large, leading to a smaller number of central projects. For example, not all cities in Northeast China have central projects, whereas all cities have local projects. As a result, there are more nodes and linkages in the network for local projects. Secondly, cross-regional/provincial GPA connections emerged as more common in the regional networks for central projects. For example, the interregion GPA connections were found to be weaker than the within-region GPA connections in the networks for local projects when comparing the networks at the regional and national scales, while the two showed no differences in the networks for central projects. In addition, at the regional scale, the interprovincial connections for central projects accounted for 40.09% of the overall connections, which is a larger share than that of local projects (12.75%). Moreover, also at the regional scale, the administrative boundary was found to be more important than all other factors in the network for local projects. Since projects funded by the central budget tend to have high technical requirements and heavy workloads, and firms in one region might not able to meet the project requirements, there is more cross-regional/provincial cooperation for central projects [33].

In this research, we examined the associations of spatial proximity, economic development, city population, and provincial boundaries with GPA connections. Although our analysis suggests that these factors can explain a substantial amount of the GPA connection variation in the four networks, policy can also be highly relevant. Since one of the important functions of GPA is to enable the government to play a macroregulator role in national economic development and promote the implementation of policies to safeguard domestic industries, protect the environment, and support the development of underdeveloped regions and small and medium-sized enterprises, the GPA supply–demand connections can be affected by multiple policies. For example, under the promotion of Targeted Poverty Alleviation policies, the country and provinces have allocated more projects focused on industrial development and infrastructure construction in poor areas. Therefore, cities in

Table 9: Comparison with other urban network studies.

Other study cases	Type of urban network	Similarities	Differences
[48]	Intrafirm	Factors of economy and population are positively associated with the city's status in the network	Connection data
[22]	Interfirm	Provincial capitals play important roles	
[49]	Population	Administrative borders strongly affect intercity connections	
[44]	Information/intra-firm	Regional economy and policy guidance affect the regional network structure characteristics; main central cities such as subprovincial cities are same	Connection data; some poor cities are with high degree centrality in GPA network
[40]	Technology	Factors of geographical proximity are negatively associated with the connections between cities; main central cities such as subprovincial cities are same	
[43]	Transportation	Main central cities such as subprovincial cities are same	

poverty-stricken areas play a more important role in the GPA network than what is observed in the transportation, information, and innovation networks [40, 43, 44]. In addition, local governments often have preferential purchase policies for small and medium-sized enterprises, which greatly help these enterprises develop GPA connections with other places.

Both similarities and differences emerged between our study and other urban network studies. As shown in the Table 9, regarding similarities, as the GPA connection is also part of the interactions between cites, factors associated with network structure are generally consistent with the research results obtained based on other types of urban networks. That is, cities with high economic strength, population size, and high administrative level play dominant roles in the network [22, 44, 48]. Geographical distance and administrative boundaries could block the interactions between cities [40, 49]. In terms of differences, the connection data in our study is different from the previous types of urban network studies. The GPA connections between cities are supply-demand relationships and include a special entity, government, while the government can not only participate in market activities, but also regulate market activities [33]. As a result, the cities with high degree centrality in GPA network are a bit different from other types of networks. While poor cities such as Yanbian and Baicheng are marginalized in the transportation, technology, information, and intrafirm networks [40, 43, 44], they were also found to be key nodes with high degree centrality in the regional GPA connection networks.

This research provides an analysis of the extra-firm relationships between governments and firms. We constructed GPA connection-based urban networks of Northeast China at the regional and national scales, analyzed the network characteristics, and examined the factors associated with GPA connections. This research contributes to the literature on urban networks and enriches the field of urban geography. Our method could be used to construct GPA connection networks for other regions in China or other countries. The research findings of this empirical study can help governments and firms in Northeast China gain a better understanding of their roles in regional and national GPA connection networks. However, the urban networks constructed in this study focus mainly on the number of GPA connections between cities and do not differentiate between different types of procurement (such as goods and services). Future research could further examine the nuances related to varying types of procurement. Incorporating GPA records over multiple years into the network construction in future work could also provide important insights into the spatiotemporal evolution of urban networks.

This research also offers important policy implications. The negative net outdegrees of cities in Northeast China in the national GPA networks indicate that the region mainly imports services/goods from other regions. Furthermore, firms outside the cities of Harbin, Changchun, Shenyang, and Dalian play only a minimal role in the regional networks. Thus, it remains important to improve the competitiveness of firms in Northeast China to improve the status and role of cities in the region. Northeast China will need to further improve its reform of industrial structure and state-owned firms to increase the region's market vitality and improve the self-reliance of the regional economy, so as to provide a good market environment for the development of firms [50, 51]. Meanwhile, governments should consider improving multiple policies, including their fiscal and taxation policies, financial policies, technological innovation policies, and talent policies, to promote the development of small- and medium-sized enterprises across the region [52]. Eventually, the four subprovincial cities should play roles as "gatekeepers" well for the three provinces. They should constantly learn the advanced experience from eastern coastal cities or regions so as to attract the gathering of advantageous firms and drive the economic development of other cities in Northeast China through technological spillovers such as hierarchical diffusion and proximity diffusion [40]. Our research also suggests that provincial boundaries play an important role in the regional network for local projects. The governments of the three provinces in Northeast China should encourage wider cooperation and establish purchasing standards to better guide the allocation of industrial resources and support the sustainable development of the region. At the same time, Jilin province should make good use of its central location in the three provinces. It could consider establishing economic cooperation with the Shenyang Economic Zone to the south and steadily building "Ha-Chang" urban agglomerations to the north. As a result, Northeast China could strengthen regional economic ties and achieve the goal of optimizing its regional spatial layout [50].

5. Conclusions

This study takes Northeast China as a case study to construct urban networks based on extra-firm relationships between governments and firms. This work contributes to the literature on urban network studies and enriches the field of urban geography. Through an analysis of the characteristics of network structure and the factors associated with GPA connections, we found that the capital cities of the provinces play important roles across all networks. While they serve as the GPA suppliers in the region, nationally, they mainly serve as the consumers. The factors of spatial proximity, economic development, population, and provincial boundaries were found to be significantly associated with the amount of GPA connections in one or multiple GPA connection networks. Our study helps identify the important role of cities and city dyads with regard to the extra-firm connections between governments and firms in one region. This study also provides important insights into the different roles that cities might play at different spatial scales. This research can be used to formulate effective strategies to help improve a city's competitiveness and cities' cooperation within a GPA network.

Data Availability

The data of GPA transaction records could be obtained from http://www.ccgp.gov.cn/. And the socioeconomic data of cities could be collected from Statistical Yearbook of China's Cities and the Statistical Yearbook of the Province.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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