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*Article*

# Evolution Characteristics and Influencing Factors of City Networks in China: A Case Study of Cross-Regional Automobile Enterprises

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**Abstract:** The optimization of the spatial structure of the city network is conducive to the scientific spatial distribution of industries and the promotion of coordinated regional development. This study selected the top 100 automobile enterprises in the Chinese stock market that belong to China's pillar industry, a total of 1455 headquarters and branches, to establish an enterprise matrix. Based on the ownership linkage model, the evolution characteristics of city networks in China from 2000 to 2020 are revealed, and the influential factors of city networks are discussed using the negative binomial regression model. The findings are as follows: (1) there are significant differences in the status of automobile cities, forming a "pyramid network" hierarchy. (2) The agglomeration area of automobile cities has formed the development region of "4 + 4 + 1". (3) The city network with hierarchical connections has formed a spatial structure of a "cross–cobweb" in the middle and "trapezoid–diamond" in the periphery. (4) Urban transportation conditions, the scientific research environment, the enterprise agglomeration economy, GDP per capita, and technological proximity positively impact the formation of a city network, but the total export–import volume has a negative impact. Overall, the government can use this study's results to formulate policies for the automotive industry and urban development.

**Keywords:** cross-regional; automobile enterprises; city network; evolution characteristics; influencing factors; China



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## 1. Introduction

Regional integration and urban agglomeration cooperation are the top priorities while promoting coordinated regional development. The extensive development of China's cities has led to uneven regional linkages and economic development [1]. With further globalization, the flow of people, logistics, and capital between cities has become increasingly frequent, leading to a city network structure between regions. Exploring the structure of city networks and influencing factors has become a foothold for promoting industrial economic growth and studying new regional development patterns [2].

The complete city network is the sum of all "space of flows," including human traffic, logistics, and financial flows, which form a global network overlaid with all functional networks. However, due to the difficulty of obtaining overall data, the study of city networks is based on the functional networks of certain flow spaces, also referred to as the "agents" of city networks, such as traffic flow [3], logistics, or enterprise flow [4,5]. However, city networks based on traffic or logistics contain relatively simple information and reflect more common knowledge [6]. The rapid development of globalization has driven a major global division of labor in corporate production. In contrast, the production segmentation of corporate value chains has driven changes in global and regional urban systems. Enterprises, as a collection of resources, such as knowledge, capital, technology, and talent, are embedded in cities through the regional layout of their head offices and are connected to other cities to form the enterprise flow with the attributes of network organization, which breaks through the limitations of geographic distance and becomes a key driving force in shaping the city network [7]. Consequently, using enterprise networks formed by enterprise flow as "agents" of city networks and utilizing them to study urban networks have become an important regional research direction in recent years [7,8]. Many scholars have used advanced producer services (APSs) and transnational corporations as agents to study city network systems [9,10]; however, these studies have largely focused on the dominant position of "global cities," such as New York, London, and Tokyo in the global city network. The extant literature lacks attention to more economically underdeveloped edge cities [11,12] and is insufficient to fully reveal the structural characteristics and power hierarchy in the evolution of city networks. As a representative of developing countries, there are several economically underdeveloped edge cities in China, and it is difficult for APS-based city network research to uncover the characteristics of the Chinese city network. Therefore, it is necessary to choose an enterprise network suitable for China's economic development as an "agent" for study.

China's flourishing auto industry has established a nationwide production system under the government's auto joint venture policy and the strategic guidance of auto multinationals. In 2022, China's automobile production reached 27.02 million units, and the industry has become the pillar industry of China's national economy [13]. Thus, considering the theory of comparative advantage, Chinese automobile enterprises compare the cost in different regions under the premise of maximizing benefits, and their technology and production centers are located in different cities [14]. The geographical distribution pattern under the physical space constitutes a dense network of enterprises, which depend on the city to form a network of cities so that the inter-city correlation is gradually strengthened, which strengthens the regional economy, as well as the formation and the rapid development of the metropolitan area. Although the Chinese automotive industry has made significant achievements in its production scale, it is still in the downstream stage of the industry in the global production network system [15]. Unpredictable factors, such as the COVID-19 outbreak, have profoundly affected the production environment of the global automotive industry chain. The economic linkages of numerous cities have been dramatically impacted, representing a gradual shift in the automotive enterprise network from local agglomeration to a cross-regional output model, further emphasizing the importance of cross-regional economic linkages for the industry [16]. The ability of cities to agglomerate enterprise networks also indirectly affects the development history of their regions and becomes an essential engine of regional linkage. This has led to diverse types of networked city networks based on automotive enterprise networks in China. Through the connections between the automobile enterprise network and the city, on the one hand, we can analyze the layout pattern of Chinese automobile enterprises and understand the characteristics of technical connections within enterprises. On the other hand, network analysis can be used to explore the influence and differences in the automobile industry in different cities in China. Theoretically, this study explores the city hierarchy and inter-city linkage structure based on automobile enterprises in multiple periods and dimensions. It also investigates the influence of city attributes and proximity variables on city networks, further improving the logical framework of the structural characteristics and influencing factors of city networks. At the practical level, this study aims to guide the automobile industry to carry out a reasonable geographical division of labor and promote the region's balanced development.

The analytical framework of this study is shown in Figure 1. According to the collected data on the total branches of automobile enterprises and the geographic location of the city, a city network model based on the network of automobile enterprises is constructed. The evolution characteristics of the city network are analyzed in terms of the attributes of the nodes within the network, the node agglomeration mode, and the linkage structure. Based on the spatial structure, the factors influencing the network formation and guiding the automobile industry's planning are further explored to achieve a reasonable geographical division of labor. From the analysis of evolution characteristics to the analysis of influencing factors, the research framework of urban networks is improved to a certain extent, and it can also be applied to other urban network studies based on enterprise networks. As a result, this study aims to solve three problems. First, we aim to determine the urban distribution mode from the perspective of automobile enterprises. Second, we uncover the characteristics of city network connections from the perspective of automobile enterprises, and third, we determine the influencing factors of the city network. The remainder of this study is structured as follows: the Section 2 reviews the relevant network literature from the perspective of automobile enterprises, and the Section 3 elaborates on the acquisition of enterprise data and the construction method of the city network model. Moreover, the Section 4 analyzes the evolutionary characteristics of city networks, and the Section 5 uses panel data to build a negative binomial regression model and explores the influencing factors. The Section 6 summarizes problems for future studies.

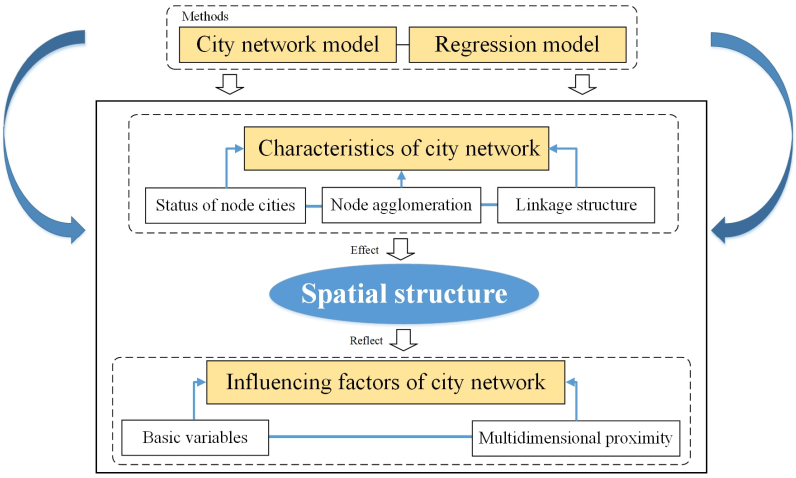


**Figure 1.** Analytical framework.

## 2. Literature Review

The study of world city networks using enterprise networks as "agents" is a research method that has become a paradigm in city network research. It explores the economic links and status of cities by analyzing the links between cities in enterprise networks [17,18]. However, this perspective has been questioned for its excessive focus on the "global north" [12], which cannot be applied in many developing countries. Most studies evaluate city networks through APS firms [19], which cannot be applied to studies of city networks in China, where there are few APS firms. A city network can be regarded as a structure of economic exchange based on information and capital [20]. The automobile industry comprises five parts: vehicle design, parts manufacturing, automobile service manufacturing-related industries, and after-sales systems. The substantial industrial chain structure takes different levels of cities as "agents," and the relationship among capital, technology, and labor flow among them gives rise to economic cooperation among cities. Chinese automotive enterprises have gradually developed from spatial disorders to polycentric clusters, and it is essential to further examine the characteristics and mechanisms of Chinese city networks based on the economic ties of automotive enterprises.

### 2.1. Correlation between Automobile Enterprise Networks and Cities

The automotive industry has been a critical driver of global production linkages. The spatial layout of the automotive supply and innovation chain systems have driven the course of urban linkages and high production-driven economic growth, serving as a constant driving force for city networks characterized by economic attributes. The automobile industry chain comprises powerful capital and technological innovation industries, which must match the city's population, policy, and economic strength. Specifically, the core cities in the automobile production network can rely on the proliferation of industrial chains to develop linkages with lower-ranking edge cities and enhance regional economic strength. Many urban researchers have analyzed how the organizational form of many enterprise networks relates to cities. The cluster model among enterprises was first applied in the automobile enterprise network [21]. The early Ford production model was a characteristic of the industrial cluster. The centralized production of various parts was due to the highly cooperative performance of the local enterprise network, which connected the primary regions within the city, namely, the intracity network. This form can effectively produce the agglomeration economy effect and take advantage of geographical proximity to reduce innovation costs, promote local knowledge spillovers [22], and ultimately promote urban economic development. Nonetheless, excessive local industrial agglomeration is limited to specific areas in a single city, and the increase in competition gradually produces an "agglomeration shadow" [23]. Therefore, scholars believe it is necessary to establish connections with industrial clusters in other cities to expand competitive advantages and promote the integrated development of urban and industrial systems [24]. The cross-regional connection of industrial clusters inevitably supports resource exchange within the city, and the city plays a vital intermediary role in promoting the connection of industrial clusters.

Following the trend of globalization, considering factors, such as the population, labor force, and industrial cost, many enterprises have rapidly changed from the former local industrial cluster mode to the cross-regional layout mode dominated by cost factors [25]. The literature has shown that industrial clusters in different cities have formed a "global cluster network" through the cooperation of supply chain, capital, and technology, thus integrating into the global pipeline [26]. Driven by enterprise networks, complex city networks are formed among cities and promote local industrial upgrading and economic development, i.e., intercity networks. This model mainly initially focuses on auto parts enterprises in some European countries. They take cities with lower production costs as their primary targets, thus driving the connection between core and peripheral cities [27], promoting the sustainable development of auto enterprises and the economic development of cities toward functional specialization. Some scholars have explored how the Jakarta metropolitan area integrated into the world city network and how this altered its urbanization process from the manufacturing network perspective instead of a developed and underdeveloped social–spatial structure [28]. Companies with power advantages in Canadian automobile clusters occupy a central position in the production network, which controls the flow of the urban industrial economy and emphasizes policies and strategies of the mutual support of cities [29]. Most city network studies based on automobile enterprises in China are from the perspective of the automobile supply chain, focusing on the ordering of city status [30,31] and have not yet explored the spatial structure and influencing factors from a multi-dimensional perspective.

### *2.2. Factors Influencing City Networks*

The literature on factors influencing city networks is scarce, and most studies are based on a static or dynamic descriptive analysis of city networks [32,33]. Part of the reason for this may be that selecting influencing factors and statistical methods is difficult. Discussing city network factors under automobile enterprises is mainly based on analyzing industrial clusters inside the city. Additionally, most scholars mainly study the urban network formation of the APS industry, and most of the indicators are selected using the attribute indicators of cities. Some studies analyzed the observed network patterns using city attributes and the network structure [34]. Boschma established a technical framework for multidimensional proximity and explained the formation logic based on innovative interaction [35]. This method supplemented the proximity index and increased the selectivity of influencing factors [36]. The combination of urban attributes and multidimensional proximity is more explanatory of forming a city network.

In summary, in the research on city networks based on the network of automobile enterprises, most of the literature has only focused on a single time slice, and the analysis of spatial evolution characteristics is limited to the ranking of the urban status. Similarly, the research objects and factors selected for the study of influencing factors have not been deeply explored. This study selects three time slices to analyze the evolution characteristics of a city network from the perspectives of node attributes, node aggregation patterns, and connection structures. It also classifies the research objects and influencing factors for discussion and analyzes the spatial structure and influencing mechanisms from multiple dimensions. This can further promote the theoretical progress of urban networks based on enterprise networks and guide the rational layout of the automotive industry.

## 3. Research Data and Method

### *3.1. Research Data*

A list of companies was obtained from China Business Intelligence (www.chnci.com, accessed on 5 January 2022), which collects the top 100 Chinese automotive enterprises as of 30 December 2020, the closing of the stock market. The top 100 companies are ranked based on market capitalization in the financial market. A data comparison reveals that the total market capitalization of the collected list of enterprise data accounts for 93% of the market capitalization of all listed Chinese automotive enterprises, which is representative of the industry.

The specific enterprise data of the headquarters and branches are from the official website of Tianyan Research (www.tianyancha.com, accessed on 15 January 2022). The data of more than two (including two) automobile enterprises in mainland China were collected and screened. These data include production, research, sales, and service enterprises. The total investment of branches had to exceed 50%, and irrelevant enterprises were excluded. Prefecture-level cities and above were the basic attribute units, while district and county administrative areas were classified into prefecture-level city units for consolidation.

The list of enterprises includes the top 100 listed automobile enterprises and their investment holdings, totaling 1445 enterprises distributed in 141 prefecture-level cities across China. The evolution characteristics of China's city network based on automobile enterprises were analyzed in 2000, 2010, and 2020, and the enterprise organizations are divided into five major categories: enterprise headquarters, branches, holding subsidiaries, branches of holding organizations, and enterprise offices. The 141 prefecture-level cities represent 48% of prefecture-level cities in China and are distributed in all provinces. In addition to the cities in the economically developed eastern regions, we included economically underdeveloped local cities in the central and western regions, complementing and focusing on the "edge cities" in the city network.

### *3.2. Research Method*

Construction of a City Network Model

This study uses the ownership linkages model to construct an urban network model [37], which is widely used in the construction of city networks and can simultaneously evaluate the status of cities within the network and the city connectivity.

- Enterprise matrix model

We searched for the branch offices established by the headquarters in each city; assigned 4, 3, 2, and 1 points according to the scale; and formed an initial network matrix of 1455 × 141 cities in China.

$$\begin{bmatrix} & B_1 & B_2 & B_3 & \cdots & B_y \\ A_1 & E_{11} & E_{12} & E_{13} & \cdots & E_{1y} \\ A_2 & E_{21} & E_{22} & E_{23} & \cdots & E_{2y} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ A_x & E_{x1} & E_{x2} & E_{x3} & \cdots & E_{xy} \end{bmatrix} \quad (1)$$

Here, $A_x$ represents the total number of cities, $B_y$ represents the total number of enterprises, and $E_{xy}$ represents the points assigned to cities by headquarters and branches of enterprises. Referring to relevant research methods [38], the assignment was based on the following factors. The corporate headquarters are responsible for the research and development of core technologies and major strategies. The city where it is located scored 4 points. The branches are closely related to the headquarters and provide technology research and development. The city where it is located scores 3 points. The holding subsidiary is an intentional company in which the headquarters invests with idle capital. The city where it is located scores 2 points. The production function of the branches of holding organizations is homogeneous, and the city where they are located scores 1 point. Corporate offices generally handle business provision and information, and their city scores 1 point.

- City concentration value

The city concentration value is equal to the sum of the product of the number of total branches, and the weight reflects the attraction of the major automobile enterprises gathered in the city. It also indicates the city's superior ability to develop automobile enterprises.

$$P_m = \sum_{a=1}^{y} \left[ (A_{ma} \times Q_1 + A_{mab_1} \times Q_2 + A_{mab_2} \times Q_3 + A_{mab_3} \times Q_4 + A_{mab_4} \times Q_5) \times S_n \right] \quad (2)$$

Here, $P_m$ is the centralized value of city $m$, $y$ is equal to the total number of enterprises, and $A_{ma}$ represents the headquarters of enterprise $a$ in city $m$. $A_{mab1}$, $A_{mab2}$, $A_{mab3}$, and $A_{mab4}$ represent the branches, holding subsidiaries, branches of holding organizations, and offices, respectively, of enterprise $a$ in city $m$. $Q_1$, $Q_2$, $Q_3$, $Q_4$, and $Q_5$ are the scores corresponding to each institution in the matrix model, which are 4, 3, 2, 1, and 1, respectively. Furthermore, considering the influence of enterprise market capitalization on the city, K-means clustering was used to divide all automotive enterprises' market capitalization $S_n$ into five subsets, which were recorded as 5, 4, 3, 2, and 1 points.

- City connection value

The connection value represents the business flow of the enterprise in different cities. The city where the headquarters and branches are located represents the sending and receiving nodes of the connection value. The data are normalized to reflect the cooperation intensity of the city network.

$$R_{mn} = \sum_{a=1}^{y} r_a(m,n) + \sum_{a=1}^{y} r_a(n,m) \quad (3)$$

Here, $R_{mn}$ represents the connection value between city combination $r_a(m,n)$ plus the reverse connections between each other. The connection value is based on the firm–city transformation matrix model and the assignment method. The linkage intensity of the total branch of the firm is transformed into the city connection value. For example, enterprise $a$'s headquarters is in city $m$, and the branch office is in city $n$; thus, the linkage intensity of city combination $(m,n)$ is 3, and the final connection value is accumulated.

### 3.3. The Construction of the Regression Model

The influence of the independent variable of the regression model in this study on the dependent variable has a time-lag effect; moreover, the influence of the independent variables on the connection value of the city network cannot be completed rapidly. Simultaneously, to avoid endogenous influences between data and make them comparable, the independent variables were taken with a lag of 1 period and standardized. Finally, data from 1999, 2009, and 2019 were obtained to build the panel data model. Since the dependent variable is a counting variable and the difference between mean and variance is large, meaning there is "excessive dispersion," a panel-negative binomial regression model was adopted and calculated in Stata 16. The Hausman test was significant, so a fixed-effects model was used.

$$Y_{mn,t} = \sum_{x \in X} a^x A^x{}_{m,t} + \sum_{y \in Y} b^y \beta^y{}_{n,t} + \sum_{z \in Z} c^z proximity^z{}_{mn,t} + D + w_i + \varepsilon_{ij,t} \quad (4)$$

Here, $Y_{mn,t}$ represents the connection value between output city $m$ and input city $n$ of flow. $A^x_{m,t}$ are $x$th basic variables of city $m$ in year $t$. $\beta^y_{n,t}$ are $y$th basic variables of city $n$ in year $t$. Furthermore, $proximity^z_{mn,t}$ represents $z$th proximity variables between city $m$ and city $n$ in year $t$. $X$ and $Y$ are the basic variable sets of cities. $Z$ is the set of multidimensional neighboring variables. $a^x$, $b^y$, and $c^z$ are the set of estimated coefficients. $D$ is the constant term, $w_i$ is the individual effect, and $\varepsilon_{ij,t}$ is the stochastic disturbance term.

## 4. The Characteristics of the City Network Based on Automobile Enterprises

### 4.1. The Attribute Characteristics of Node Cities

The concentration value can reflect the status of different automobile cities in the city network. The calculation results (Figure 2) show that the status of automobile cities follows a rank-size trend, decreasing at high speed, similar to the creative city network [39]. The natural breakpoint classification method is used to divide the concentration value into four levels: national automobile cities, regional automobile cities, local automobile cities, and ordinary automobile cities. The number increases non-uniformly from top to bottom, presenting a hierarchical "pyramid network" (Table 1).

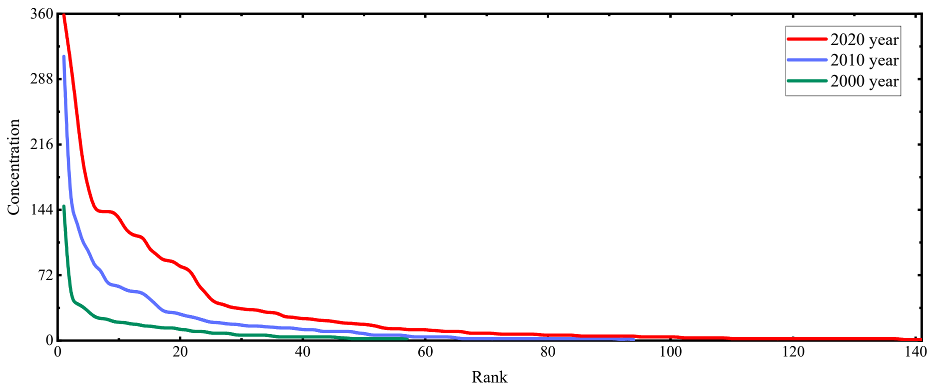


**Figure 2.** Rank size map of automobile cities.

**Table 1.** The urban hierarchy of automobile enterprises.

| City Level | 2000 | | 2010 | | 2020 | |
|---|---|---|---|---|---|---|
| | City (Concentration Value) | Ratio | City (Concentration Value) | Ratio | City (Concentration Value) | Ratio |
| National automobile city (Level I) | Shanghai (148) | 2% | Shanghai (313) | 1% | Shanghai, Chongqing, and Shenzhen (259–359) | 2% |
| Regional automobile city (Level II) | Chongqing, Changchun, Shenyang, and Guangzhou (27–46) | 9% | Beijing, Chongqing, Changchun, Baoding, Shenzhen, and Guangzhou (65–143) | 7% | Beijing, Tianjin, Guangzhou, Changchun, Baoding, Hangzhou, and 19 other cities (55–198) | 14% |
| Local automobile city (Level III) | Shenzhen, Nanjing, Ningbo, Beijing, Wuxi, Taizhou, Tianjin, Baoding, Changzhou Guiyang, and 15 other cities (11–26) | 34% | Ningbo, Weifang, Tianjin, Chengdu, Hangzhou, Nanjing, Wuxi, Shenyang, Suzhou, Zhuzhou, and 16 other cities (25–64) | 20% | Changzhou, Qingdao, Foshan, Xiangyang, Yangzhou, Yantai, Liuzhou, Zhuzhou, and 33 other cities (17–54) | 23% |
| Ordinary automobile city (Level IV) | Xi'an, Suzhou, Liuzhou, Xiangyang, Liuzhou, Haikou, Liaocheng, Chengdu, Jinan, Harbin, and 24 other cities (1–10) | 55% | Wuhan, Yangzhou, Guiyang, Yantai, Wuhu, Taizhou, Hefei, Shiyan, Liuzhou, Dalian, and 58 other cities (1–24) | 72% | Baoji, Xiangtan, Xuzhou, Yancheng, Zhenjiang, Shaoxing, Binzhou, Wenzhou, Zhenjiang, and 86 other cities (1–16) | 61% |

#### 4.1.1. Growth Characteristics of Node Cities

From the perspective of the urban growth rate, the number of cities in the city network is increasing significantly, including 44 cities in 2000, 81 cities in 2010, and 141 cities in 2020. The ratio of the number of cities in the three time cross-sections is about 1:1.8:3.2. The quantity distribution in 2000 was 2:9:34:55; in 2010, it was 1:7:20:72; and in 2020, it was 2:14:23:61. Both horizontal and vertical axes reflect a "pyramid system." The urban growth rate was about 84% from 2000 to 2010 and 74% from 2010 to 2020. The growth rate gradually slowed down. The number of national automobile cities was relatively stable, and the proportion ranged between 1% and 2%. The number of regional automobile cities increased rapidly from 4 to 19, and the proportion increased from 9% to 14%. There are many local and ordinary automobile cities, which cumulatively increased from 39 in 2000 to 119 in 2020, indicating that the layout of the automobile industry is expanding. After 2000, many emerging cities became ordinary automobile cities, and many ordinary automobile cities were upgraded into local automobile cities.

#### 4.1.2. Status Characteristics of Node Cities

From the perspective of the individual level of cities, the number of national automobile cities is very small, ranging from 148 to 359. From 2000 to 2010, only Shanghai has led (148–313). The national automobile cities in 2020 were Shanghai (359), Chongqing (313), and Shenzhen (259). These three cities comprise 18 headquarters of the top 100 automobile companies, and they are the first-level node cities of the city network. They have become the economic and technological innovation center and transportation hub of their respective regions, far ahead of other cities in terms of the administrative level or economic strength. The value range of regional automobile cities is 27–198, and there is a large gap between the top cities and the bottom cities at this level. The leading cities include Beijing (21–198), Tianjin (20–167), Guangzhou (32–144), Changchun (41–142), and Baoding (18–142). These cities also have excellent locations and good automobile production resources. They are mainly responsible for the research and development of high-tech automobiles and cross-regional production, transportation, and logistics. Many automobile-production bases are arranged here, the second-level node cities of the city network. Local (11–54) and ordinary (1–16) auto cities are the network's third- and fourth-level node cities, including Changzhou, Qingdao, Foshan, Xiangyang, and Zhuzhou. These cities are distributed in the periphery of high-grade automobile cities. Still, they play a marginal role in the network and mainly manufacture vehicles and parts.

The differences in location, economy, and external links of different cities determine the agglomeration and radiation capacity, which in turn affects the coordination and cooperation capacity of the enterprise–city network. Cities with comprehensive strength, such as Shanghai, Beijing, and Shenzhen, can drive surrounding areas to become core urban agglomeration through the continuous accumulation of production factor flow. Cities with weak industrial foundations, such as Ya'an, Xiangyang, and Baoji, can only absorb the resource radiation of high-level cities and act as low-level nodes. National and regional automobile cities have enterprises with highly developed capital, human resources, and technology, such as SAIC, BAIC, CCAG, and BYD, with strong auto industry agglomeration and radiation capacity. Local and ordinary automobile cities are unattractive to management technology and market experience, and it is not easy to have an industry cluster and spillover effect. When the city network incorporates lower-level node cities, it facilitates the exchange of various "space of flows" in different cities, which allows the city network to be improved and the degree of coordinated development of regional integration to increase gradually.

### *4.2. Evolution Characteristics of Node Agglomeration in the City Network*

The above study explored the city hierarchy within the city network to deeply explore the characteristics and development of the city network's evolution; based on the analysis of the city concentration and nuclear density, the overall performance is based on the layout characteristics of national and regional automobile cities (Figure 3) and the basic formation of agglomeration and differentiation areas.

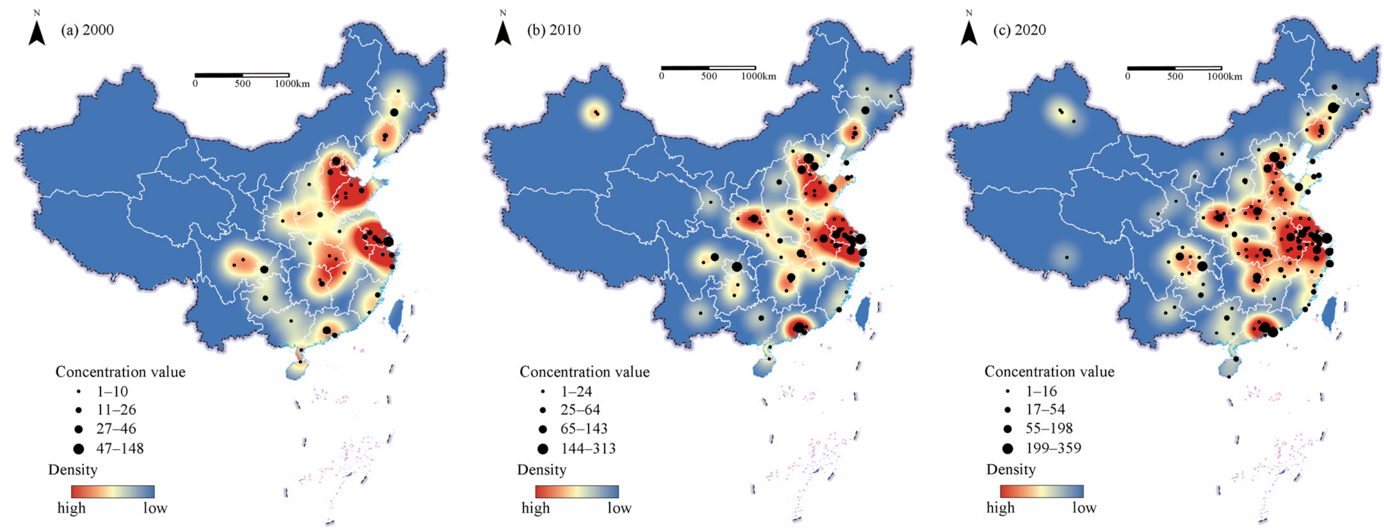


**Figure 3.** The evolution of urban agglomeration based on automobile enterprises. The three subfigures from left to right show the urban agglomeration patterns in (**a**) 2000, (**b**) 2010, and (**c**) 2020, respectively.

In 2000, the clusters mainly concentrated in the Yangtze River Delta, Beijing–Tianjin–Hebei region, and the middle reaches of the Yangtze River. The number of automobile cities in Northeast China, the Chengdu–Chongqing region, and the Guangdong–Hong Kong–Macao Bay area was small, and no good industry cluster area was formed. In 2010, the regional division of the clusters was progressively obvious, especially in the Guanzhong Plain, the Central Plains, and the middle reaches of the Yangtze River. The number and concentration of enterprises in the eastern coastal areas were further improved. In 2020, the clusters tended to be mature, and the sense of clusters in different regions was pronounced. The eastern coastal and central regions became contiguous clusters, with a core cluster in the Chengdu–Chongqing region, and the rest of the plots were distributed in scattered spots.

Regarding the distribution characteristics of the three periods of 2000, 2010, and 2020, the agglomeration system within the city network formed a development pattern of "north–south dual-line and east single-axis." The southern line is concentrated along the Yangtze River Delta and Chengdu–Chongqing region, the northern line is concentrated along the Shandong Peninsula and Guanzhong Plain, and the eastern coast and Northeast China constitute the eastern axis. Internally, this pattern can be subdivided into the development region of "4 + 4 + 1": "four cores, four auxiliaries, and one belt" urban agglomerations. The "four cores" are the Guangdong–Hong Kong–Macao Greater Bay Area, Chengdu–Chongqing urban agglomeration, Yangtze River Delta urban agglomeration, and Beijing–Tianjin–Hebei urban agglomeration. The "four auxiliaries" are the middle reaches of the Yangtze River, Central Plains, Guanzhong Plain, and Shandong Peninsula urban agglomerations. "One belt" refers to the Harbin–Changchun–Shenyang urban belt. The "four core" urban agglomerations rely on the driving force of national and regional automobile cities, such as Beijing, Chongqing, Shanghai, Tianjin, Guangzhou, and Shenzhen, forming the top cluster of city networks. "Four auxiliaries and one belt" urban agglomerations mainly rely on regional and local automobile cities for development, such as Changchun, Baoding, Hangzhou, Weifang, and Nanjing. Conversely, the rest of the region mainly relies on the agglomeration of ordinary cities for localized development, which makes it difficult to form a considerable industrial network advantage.

The strength of the accumulating trend is also closely related to national policies and local industrial development. Around 2000, the Yangtze River Delta, Beijing–Tianjin–Hebei region, and Northeast China, due to the influence of the industrial base and national industrial policies, took the lead in the layout of the national automobile industry and formed the primary city network. After 2010, under the influence of the policy for new energy vehicles and the "dual-carbon era," the "four core" urban agglomerations, with their advantages in GDP and scientific and technological talents, greatly expanded the automobile market through the research and development of technological innovation, and their development strength is in the first gradation. The "four auxiliaries" of urban agglomerations in the central and western regions are also growing, with the advantage of being the latecomer in industrial technology transformation, and their development strength is in the second gradation. Although the production capacity of the Harbin–Changchun–Shenyang urban belt is at the forefront of China, under the pressure of industrial structure transformation, the low growth rate of economic development leads to weak innovation ability and the industrial clustering effect. The production advantage is difficult to compensate for the disadvantages of other conditions, and the development strength is in the third gradation. Although Northwest China is rich in land and natural resources, it is inferior to other regions in terms of the automobile industry layout and integration of the automobile industry network due to the geographical location and inconvenient transportation.

### *4.3. Characteristics of City Network Connection*

Based on the urban agglomeration area of automobile enterprises, which forms the basis of the network connection structure, we divided the connection value into four levels (Figure 4), where the black dots in the figure represent the cities and the connecting lines between the cities represent the two parties generating the business linkages. In 2000, 2010, and 2020, there were 46, 191, and 491 links, increasing successively.

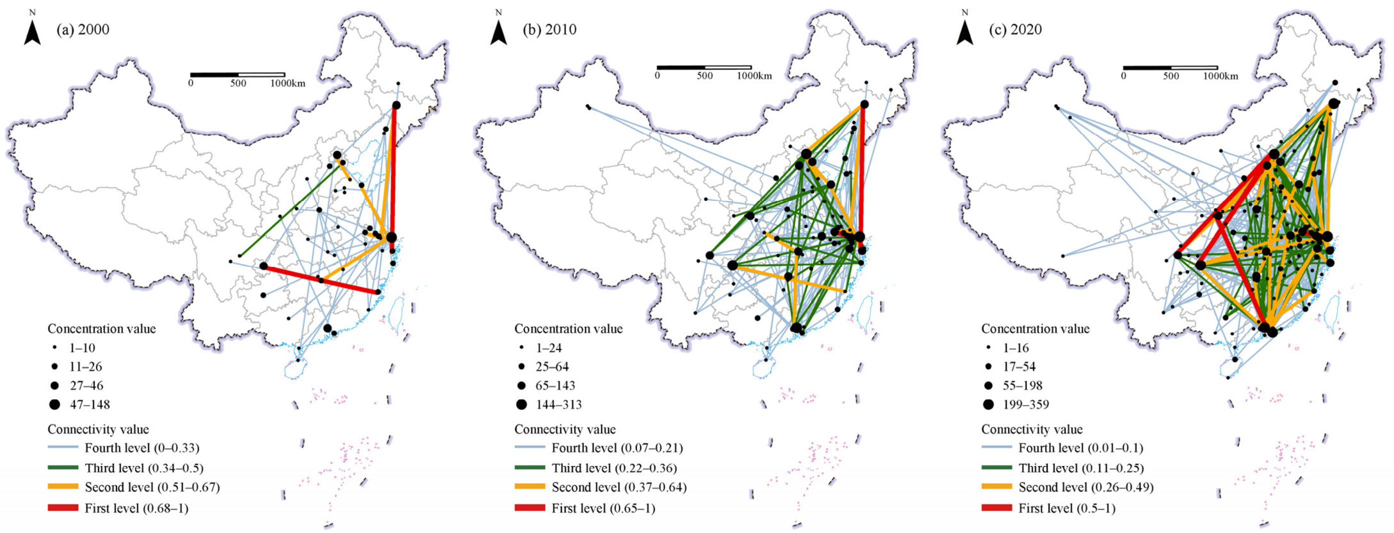


**Figure 4.** Connection value of city networks based on automobile enterprises. The three subfigures from left to right show the structure of urban connectivity in (**a**) 2000, (**b**) 2010 and (**c**) 2020, respectively.

#### 4.3.1. Overall Characteristics of the Connection Pattern

The city network generally shows a structure of a "cross–cobweb" in the middle and "trapezoid–diamond" in the periphery. It is similar to the patent city network [40] but very different from the cultural industry network [41]. From 2000 to 2020, the high-value network connection showed an apparent correlation structure called the backbone network. The five vertices of the structure of the "trapezoid–diamond" are Changchun, Beijing, Chongqing, Shanghai, and Shenzhen, and the diagonal of the "diamond" structure intersects with Wuhan. It is more of a long-distance network diffusion mode than neighboring diffusion. The northeast and central regions are closely connected with the "four core" urban agglomerations, but with great distance and more dependency on the resource radiation capacity of the core region, forming a "cross–cobweb" connection feature in the central region. Northwest China, led by Xinjiang and Tibet, has always been a weak link in the city network.

#### 4.3.2. Hierarchical Connection Characteristics

The city connections of major urban agglomerations vary greatly and have pronounced spatial directivity. The first- and second-level connections are mostly the internal output of national and regional automobile cities. Conversely, the third- and fourth-level connections are mostly the external output of national and regional automobile cities to local and ordinary automobile cities.

In 2000, the Yangtze River Delta had a high intensity of radioactive export of resources to the surrounding areas. There are two links in the first-level connections, whose intensity is between 1 and 0.68, namely Chongqing–Fuzhou and Changchun–Ningbo, which take the traditional old industrial base as the resource output point. There are six links in the second-level connections, including Shanghai–Nanjing, Shanghai–Zhuzhou, Shanghai–Weifang, Wuxi–Nanjing, Suzhou–Changchun, and Beijing–Binzhou. These second-level connections are the center-oriented type, with Shanghai as the core. The third- and fourth-level connections are mainly concentrated in the east and reduced in the west, and most are connections between local and ordinary automobile cities.

In 2010, a prototype of the "trapezoid–diamond" structure was formed. The first-level connections are Shanghai–Nanjing and Ningbo–Changchun, with a connection value between 1 and 0.65 belonging to the connection between the Yangtze River Delta region and the Harbin–Changchun–Shenyang urban belt. There are 10 links in the second-level connections, which occur in Shanghai–Weifang, Beijing–Weifang, Guangzhou–Wuhan, and Fuzhou–Chongqing. The greatest number of connections are at the third and fourth levels. Wuhan, Changsha, Shiyan, Zhengzhou, and other cities are essential supplements to automotive production and research and development (R&D) enterprises and transit points for information transfer functions.

In 2020, the "trapezoid–diamond" structure matured. The first-level connections were transferred to the east and west of the "diamond" structure, and there are six links with a connection value between 1 and 0.5, namely, Beijing–Chongqing, Beijing–Chengdu, Beijing–Baoding, Shenzhen–Xi'an, Chongqing–Baoding, and Shanghai–Nanjing. Second-level connections include all the edges of the "trapezoid–diamond" structure, and there are 26 connections in total, with a value between 0.26 and 0.49. Most third-level connections in 2010 were upgraded to second-level connections in 2020, such as Shanghai–Chongqing, Shanghai–Baoding, Beijing–Shenzhen, and Beijing–Guangzhou. In Northeast China, the connections are mainly Changchun–Shanghai, Changchun–Qingdao, and Changchun–Chengdu. The third- and fourth-level connections incorporate the general prefecture-level cities in the central and western regions into the city network, totaling 459 links. These cities are exposed to the resource radiation of the "four core" urban agglomerations and mainly gather in the northeast, Guanzhong Plain, Central Plains, and the middle reaches of the Yangtze River and the Shandong Peninsula.

## 5. Factors Influencing City Networks Based on Automobile Enterprises

### 5.1. Variable Selection

Referring to relevant studies [41,42], the factors influencing city networks are related to various socio-economic factors. The investment and layout of automobile enterprises in different cities become the driving force for the construction of urban networks, while the intrinsic capital, manpower and technology, and other resources are packaged as enterprise flow, which become the external manifestation of the structure of urban linkages, and thus the enterprise's off-site layout is the intrinsic motive of the network's influencing mechanism. The development conditions of cities are very important for the formation of urban networks under the cross-regional linkage of enterprises, and the enterprise's off-site layout must also consider the development conditions of cities. The object can be classified into the output city of enterprise flow, where the headquarters are located, and the input city of enterprise flow, where the branches are located. The variable category can be divided into the basic urban conditions and the multidimensional proximity of the city. The logical selection of reference indicators (Table 2) is as follows.

The transportation conditions, economic scale, and scientific research environment can promote city network connections. Urban transportation conditions are an important factor affecting the connections of city networks. The relationship between the spatial economy and transportation has been studied in the literature [43], and superior transportation conditions in cities can significantly reduce the commuting time for talent and technology exchange of enterprises in different locations [44], improve the transportation efficiency of raw materials and energy, and promote enterprise communication. Considering the role of special economic zones and ports, part of the impact of ports and special economic zones on cities is centered on trade revenues [45,46], and the total volume of imports and exports can affect the economic exchanges between enterprises and overseas markets, thus attracting enterprises to obtain transnational investment and promoting the establishment of corporate branches by corporate headquarters. The economic strength of cities provides enterprises with various production factors, such as information, technology, capital, and markets, which in turn influence the establishment and expansion of enterprises. The urban research environment is the core driving force for enterprise development, providing elements and platform support for enterprise innovation activities and becoming a reserve force for sustainable development and industrial transformation. Additionally, in the automobile manufacturing industry, there is a close upstream and downstream relationship between the parts industry and the vehicle industry, and the aggregation of enterprises in the upstream and downstream of the supply chain can attract the layout of new enterprises [47]. Thus, the highway mileage (Highway) represents urban transportation conditions in this study. GDP per capita (PGdp) and the total volume of imports and exports (Trade) represent a city's economic strength. Research funds (R&D) represent the urban research environment. The number of automobile enterprises (Quantity) in the city represents the enterprise agglomeration effect.

The technological, geographical, and institutional proximity under the force of intercity proximity leads automotive firms to consider the cost factor of layout, which affects city network connections [48]. The similarity of technology proximity shows that cities have a similar industrial structure. Cities with similar technology can affect the collaborative development and technology exchange of enterprises and help strengthen the cooperative relationship of city networks. Overall, geographical proximity can reduce the transportation cost of enterprise connection and improve the convenience of resource and market acquisition [49]. Institutional proximity includes similar policy rules and city levels [50], which can optimize the connection environment of a city network. In this study, we borrow the similar coefficient of industrial structure (Isc) proposed by UNIDO to represent technological proximity based on its concept. The geographical distance (Geo) between cities is converted by latitude and longitude to represent geographical proximity. Using the relationship (Adi) between administrative regions to represent the institutional proximity, the score for cities above the sub-provincial level is four for both parties, two for cities above the sub-provincial level for one party, and one for other prefecture-level cities. The formulas for the similarity coefficient of an industrial organization and the geographic distance between two points are as follows (Table 3).

**Table 2.** Data interpretation and source.

| Variable Category | Variable Name | Variable Interpretation | Data Sources |
|---|---|---|---|
| Transport conditions | Highway | Highway mileage | China City Statistical Yearbook |
| Economic strength | PGdp | GDP per capita | China City Statistical Yearbook |
| | Trade | Total volume of imports and exports | China City Statistical Yearbook |
| Research environment | R&D | Research funds | China City Statistical Yearbook |
| Enterprise agglomeration effect | Quantity | Number of automobile enterprises | https://www.tianyancha.com/ |
| Technological proximity | Isc | Similarity coefficient of the industrial structure both cities | China City Statistical Yearbook |
| Geographical proximity | Geo | Geographical distance of both cities | https://map.baidu.com/ |
| Institutional proximity | Adi | The administrative level of both cities | Opinions on Certain Issues of Sub-Provincial Cities |

**Table 3.** Formula for geographic and institutional proximity.

| Proximity Factor | Formula | Interpretation |
|---|---|---|
| Technological proximity | $S_{ij} = \sum_{k=1}^{n} x_{ik}x_{jk} / \sqrt{\sum_{k=1}^{n} x_{ik}^2 \sum_{k=1}^{n} x_{jk}^2}$ | $S_{ij}$ is the similarity coefficient of industrial structure; $x_{ik}$ and $x_{jk}$ are the output value of industry $k$ in city $i$ and $j$. $S_{ij}$ takes a value ranging from 0 to 1, and the higher the value, the higher the degree of similarity in the industrial structure. |
| Geographical proximity | $D = R \times \arccos[\sin(\text{lat1}) \times \sin(\text{lat2}) + \cos(\text{lat1}) \times \cos(\text{lat2}) \times \cos(\text{lon2} - \text{lon1})]$ | $D$ is the spherical distance between the two points. $R$ is the mean radius of the Earth. lat1 and lat2 are the latitudes of the two points, and lon1 and lon2 are the longitudes of the two points. |

### 5.2. Results

This study introduces different variables into the regression model for discussion. Models 1–2 consider the primary variables of the output city of flow, models 3–4 consider the basic variables of the input city of flow, and models 5–7 combine the essential variables and multidimensional proximity. The specific analysis results (Table 4) were as follows.

**Table 4.** Results of negative binomial regression.

| Variable Category | Model 1 | Model 2 | Model 3 | Model 4 | Model 5 | Model 6 | Model 7 |
|---|---|---|---|---|---|---|---|
| Basic variables of output city of flow | | | | | | | |
| Highway (km) | 1.0717 *** | 0.7772 * | | | 0.4659 | 0.4433 | 0.5180 |
| | (2.95) | (1.86) | | | (1.24) | (1.15) | (1.30) |
| PGdp (CNY) | 1.2460 *** | 1.0833 *** | | | 0.3775 | −0.3794 | −0.3463 |
| | (4.94) | (3.88) | | | (−1.25) | (−1.26) | (−1.15) |
| Trade (CNY) | 0.1535 | 0.1291 | | | 0.3736 * | 0.3746 * | 0.3856 * |
| | (0.64) | (0.54) | | | (1.70) | (1.70) | (1.76) |
| R&D (CNY) | 0.8189 *** | 0.9679 *** | | | 1.0760 *** | 1.0766 *** | 1.0537 *** |
| | (2.78) | (3.08) | | | (3.90) | (3.90) | (3.82) |
| Quantity (each) | | 0.4811 | | | 0.1345 | 0.1386 | 0.0780 |
| | | (1.39) | | | (0.44) | (0.46) | (0.25) |
| Basic variables of input city of flow | | | | | | | |
| Highway (km) | | | 2.3875 *** | 1.3287 *** | 1.3554 *** | 1.3347 *** | 1.4125 *** |
| | | | (6.90) | (2.96) | (3.29) | (3.18) | (3.29) |
| PGdp (CNY) | | | 2.2452 *** | 2.0086 *** | 1.4033 *** | 1.4105 *** | 1.3981 *** |
| | | | (10.44) | (8.90) | (4.58) | (4.59) | (4.59) |
| Trade (CNY) | | | −0.9786 *** | −1.2598 *** | −0.7932 ** | −0.8007 ** | −0.8200 ** |
| | | | (−2.63) | (−3.24) | (−2.11) | (−2.12) | (−2.19) |
| R&D (CNY) | | | 0.2204 | 0.6349 | 0.6914 | 0.6987 | 0.7392 * |
| | | | (0.49) | (1.34) | (1.56) | (1.57) | (1.67) |
| Quantity (each) | | | | 1.4924 *** | 0.7633 * | 0.7723 * | 0.7037 * |
| | | | | (3.56) | (1.84) | (1.86) | (1.66) |
| Multidimensional proximity variables | | | | | | | |
| Isc | | | | | 1.3371 * | 1.3366 * | 1.4097 * |
| | | | | | (1.67) | (1.66) | (1.74) |
| Geo (km) | | | | | | 0.0674 | 0.1149 |
| | | | | | | (0.26) | (0.44) |
| Adi | | | | | | | −0.1902 |
| | | | | | | | (−0.81) |
| Constant term | 0.9411 *** | 0.9957 *** | 0.9667 *** | 1.1220 *** | 0.4649 | 0.4531 | 0.5214 |
| | (4.26) | (4.42) | (3.53) | (4.13) | (0.53) | (0.51) | (0.57) |

Notes: * = $p < 0.1$, ** = $p < 0.05$, and *** = $p < 0.01$. Standard errors are shown in parentheses.

Models 1–2 are dominated by the output city of flow, showing that the significant levels of external transportation conditions and the research environment are positively correlated. This result indicates that the convenient transportation and scientific research level of cities can positively influence the flow output, thus strengthening the connection of city networks. Economic geography indicates that any cross-regional product production and sales need to consider cost factors and that greater high-speed mileage enhances accessibility. The superior scientific research strength of the city can provide sufficient scientific research funds and promote the flow output. GDP per capita has a positive impact, while the total volume of imports and exports has no significant impact. China's automotive technology has lacked high-end chip R&D technology in recent years, and the import of core technology products is weak. Foreign economic exchanges from total imports and exports hardly give an advantage to the external linkages of cities based on the flow of automotive enterprises.

Models 3–4 are dominated by the input city of flow, transportation conditions, and enterprise agglomeration economy, which contribute to the input of automobile enterprise flow. The agglomeration of the number of enterprises indicates that enterprise branches choose cities with good industrial foundations. GDP per capita also has a positive impact, while the total volume of imports and exports has a significant negative impact, which means that cities with fewer trade imports and exports support the input of enterprise flow. Because some of the input cities of flow assume the function of parts manufacturing, auto repair, and sales service, they do not need much external market exchange. Cities with developed foreign economies generally have higher labor costs; therefore, the areas with fewer imports and exports contribute to city network connections in the input city of flow.

Models 5–7 integrate the first two types and multidimensional proximity variables, among which the significance of the primary variables is similar to that of the previous four models, and this model pays more attention to the results of multidimensional proximity indicators. The results show that cities with similar technological proximity are more likely to form intercity connections. The geographic proximity variable is insignificant due to the rapid development of information technology, which allows knowledge to be coded and transmitted. Some scholars have also proposed the "geographic death theory," which states that information technology transmission makes geographic distance less sensitive. Institutional proximity also does not provide a connection advantage to the city network, which indicates that the interventionary role of the government is weakening. The flow of production factors under the market economy system might change the intercity connection mode, with the characteristics of spontaneous communication.

## 6. Conclusions and Reflections

### *6.1. Conclusions*

This study explores the characteristics of China's city network from 2000 to 2020 while considering automotive companies, which can represent China's manufacturing business model. As an example, this study builds a negative binomial regression model with panel data to explore the factors influencing a city network. This study contributes to city network theory and the connection modes and causes related to industrial networks in China, which can be summarized as follows.

The polarization of the control of automobile resources is evident within China's city network, which can be divided into four levels: a national auto city, a regional auto city, a local auto city, and an ordinary auto city, showing the characteristics of a "pyramid network." The agglomeration pattern within the city network has evolved into a "north–south dual-line and east single-axis" pattern. Internally, it can be subdivided into the regional development mode of "four cores + four auxiliaries + one belt." From south to north, the "four cores" are the Guangdong–Hong Kong–Macao Greater Bay Area, Chengdu–Chongqing urban agglomeration, Yangtze River Delta urban agglomeration, and Beijing–Tianjin–Hebei urban agglomeration. The "four auxiliaries" from south to north are the middle reaches of the Yangtze River, Central Plains, Guanzhong Plain, and Shandong Peninsula urban agglomerations. "One belt" comprises the Harbin–Changchun–Shenyang urban agglomeration. City connections are highly unbalanced, with the spatial structure of a "cross–cobweb" in the middle and "trapezoid–diamond" in the periphery. The five vertices of the composite structure are Changchun, Beijing, Chongqing, Shanghai, and Shenzhen. The network connection is outputted from the national and regional automobile cities.

The city network is influenced by both the output and the input city of flow. The transportation conditions, research environment, enterprise agglomeration economy, and GDP per capita of cities are important factors influencing city networks, but the degree of influence varies. The urban scientific research environment is the core factor in all the models, with the output city of flow as the object; however, taking the input city of flow as the object, urban transportation conditions, GDP per capita, and enterprise agglomeration economy are the core factors necessary to strengthen intercity linkages. The total export–import volume is a negative factor for the input city of flow into the city network, as such cities mostly assume production and sales services and do not require much external market exchange. Only technological proximity among the multidimensional proximity variables can positively promote the formation of a city network; moreover, cities with similar technology structures can better promote knowledge spillovers and intercity linkages. The flow of various production factors reduces the interference of geographical distance and institutional factors.

### 6.2. Discussions

This study focuses on the automobile manufacturing industry, which represents China's national economy, and it analyzes city networks suitable to determine the characteristics of China's economic development. It focuses on the city hierarchy and linkage characteristics in the city network based on automobile enterprises and combines the city attribute and proximity variables to analyze the research object. Thus, this study complements the shortcomings of previous studies that focus only on city hierarchies and considers diversified variables in the influence mechanism. This logical model completes the research framework of city networks based on automobile enterprises and supports the generation of conclusions.

Based on the above conclusions, this study proposes the following policies for city networks based on automobile enterprises: (a) the construction of advantageous clusters should be consolidated into a city network. Efforts should be made to expand the automobile production capacity in the Beijing–Tianjin–Hebei region, the Yangtze River Delta, the Chengdu–Chongqing region, and the Guangdong–Hong Kong–Macao Greater Bay area while pooling policy, economic, and human resources to promote the integration of Shanghai, Chongqing, Shenzhen, and other cities into the global automobile network. (b) The importance of the linkage effect between regions should be highlighted. The government should focus on forming local industrial clusters and constructing foreign transportation to expand intercity linkages. Efforts should be made to improve the economic and scientific research strength of cities, support the formation of linkage centers between core cities and local cities, and improve the R&D and exchange capabilities of automotive technology between regions. (c) The borrow size capacity of ordinary cities in the network should be enhanced. The government should locate high-tech and R&D enterprises in cities with advanced automobile technology and economies, whereas lower-cost production and logistics companies should be located in lower-grade cities. Using industrial network connections, the government should promote regional synergy and integrate ordinary cities into the city network while promoting automobile industry construction in the disadvantaged areas in the northwest to enhance network externality.

### 6.3. Reflections

Despite focusing on the urban network based on the cross-regional automotive industry, this study still has some limitations. Spatial statistical measurement modeling has not yet been used to reflect the mechanism of influence of location and space. In the future, we will use complex networks based on different flow spaces to propose solutions to more industries and regional development problems.

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