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Visualizing the Chinese Cyberspace: a Spatial-temporal Analysis (2012–2019)

Abstract: Despite growing interest in understanding urban networks in cyberspace, data availability remains a significant challenge, as few studies have systematically visualized the entirety of cyberspace networks. Using the Baidu Index, which tracks the exposure of cities in online media and their search activity by users in other cities, this analysis visualizes and examines the urban networks of 296 Chinese cities from 2012 to 2019. Our findings highlight the following key insights. The spatial distribution of web search activity forms a diamond pattern, with the four core regions of Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, and Chengdu-Chongqing serving as the main vertices. Within this configuration, the most popular cities are predominantly located in eastern China, reflecting both its advanced economic development and substantial urbanization. While the uneven pattern of online connectivity has narrowed from 2012 to 2019, the network structure in cyberspace is strongly associated with traditional factors such as population size, economic capacity, and geographical proximity. Besides, cyberspace creates new opportunities for peripheral cities to elevate their online visibility and thus partially reshape local or sub-regional networks, offering an alternative pathway for certain mid-western cities. This reshaping is evident in the increased inbound attention to cities like Chengdu and Urumqi, which have boosted their online presence and enhanced their positions within the urban network. Flows in cyberspace should be a vital consideration in future urban spatial planning and regional development strategies. The insights from this analysis offer valuable guidance for policy-making to redirect a portion of the digital attention to enhance the online presence of less-developed regions.

Keywords: Urban system; flows in cyberspace; spatial-temporal evolution; Baidu index; China

1. Introduction

Cities have long existed in interdependent systems, shaped by flows of people, goods, information, and capital (Castells 1996, Taylor and Derudder 2016). These multi-directional interactions effectively shrink space and time between urban nodes, constructing increasingly dense networks of exchange (Allen 2010). In this context, a city's power and relevance are shaped not only by its internal attributes, but also by its positionality within complex systems of interaction (Grubestic and Matisziw 2011, Xia et al. 2019). In the industrial era, physical proximity and face-to-face interactions were paramount, with corporate organizations and transport infrastructure serving as

key indicators of a city's prominence during the past decade (Yang et al. 2017). However, the advent of the information age has shifted focus toward digital connectivity, transforming how urban networks are conceptualized and analyzed.

Existing studies on urban networks have developed along three major methodological strands. The first focuses on infrastructure-based connectivity, using data from aviation, rail, telecommunications, and maritime systems to quantify spatial interactions (Derudder et al. 2013, Zhang and Gong 2024, Peng et al. 2023). Among these, aviation data has been particularly prominent due to its accessibility and ability to capture long-distance urban linkages. The second strand examines corporate networks, particularly through the lens of advanced producer services, as exemplified by the GaWC research group (Derudder and Taylor 2018, Neal 2012). These approaches highlight the role of multinational firms in shaping global urban hierarchies. A third and more recent strand employs scientific publications and patents to map knowledge flows and social relationships (Zhang et al. 2023, Yin and Li 2019). More recently, mobile phone signaling and mobility big data have been used to reveal functional regions, megaregional structures, and daily urban systems (Fang et al. 2025, Fang et al. 2024b, Zhang et al. 2020b), yielding unprecedented insights into population-driven urban interaction.

While existing work sheds light on digital flows and interactions, it often overlooks how cities are perceived, searched for, and discursively represented within digital environments. These forms of digital cognition, reflected in how online users seek information about cities, constitute a distinct but understudied mechanism through which digital space reshapes inter-urban relations. These limitations indicate that the research gap lies in the lack of a temporally comparable and structurally coherent perspective on the urban system in cyberspace. The rapid proliferation of the Internet has further expanded urban network analysis into cyberspace—a virtual realm where information production, consumption, and exchange increasingly define a city's visibility and competitiveness (Janc 2015). In cyberspace, a city's visibility is closely linked to its image and reputation, which in turn influence its ability to attract investments, tourists, and businesses all of which propel development (Avraham 2000, Pérez - Cornejo et al. 2023). Consequently, quantifying a city's presence in cyberspace has become an essential task for researchers and policymakers alike (Sadowski 2020, Zhang and Wang 2022). While emerging methods, such as toponym co-occurrence and social media analysis, offer insights into discursive relationships, they either remain confined to specific regions or fail to capture proactive information-seeking behaviors.

To address this gap, this analysis proposes web search activity as a novel proxy for analyzing

cyberspace-based urban networks, with a specific focus on redefining city rankings through the lens of asymmetric information flows. This approach is grounded in the internet's foundational role as an information-seeking platform: users actively search for city-related data to inform decisions on travel, investment, and policy engagement—behaviors that directly shape a city's digital visibility and economic influence (Terlouw and Denkers 2011). Unlike reactive measures of mobility or textual co-occurrences, web search activity captures proactive intent, reflecting how individuals and organizations strategically engage with cities beyond geographic or semantic constraints. This analysis leverages the Baidu index, China's largest search engine analytics platform, to systematically quantify cyberspace-driven urban networks across 296 Chinese cities from 2012 to 2019. As an open data tool, the Baidu Index provides aggregated, anonymized search volumes for user-specified keywords, enabling researchers to map temporal and spatial patterns of information demand (Wang and Loo 2019b, Zhang et al. 2017). This analysis addresses two research questions: How do search-driven information flows redistribute power within urban networks? What implications do these asymmetries hold for redefining city rankings in the digital age? By integrating the lens of digital attention into urban network studies, this analysis contributes to broader debates on urban power, digital spatiality, and the redefinition of hierarchy in the platform age.

The remainder of this paper is structured as follows. Section 2 reviews the related literature. Section 3 details the methodology, including the data sources, network generation, and methods employed in this analysis. Section 4 presents the main results, while Section 5 discusses their implications, limitations, and future research directions. Following this section, Section 6 concludes with avenues for future research.

2. Literature review

Urban studies has undergone a paradigmatic shift from analyzing the space of places to examining the space of flows, as articulated (Castells 2011). The proliferation of Information and Communication Technologies (ICTs) has fundamentally reshaped how cities connect, compete, and collaborate, elevating information flows as a critical dimension of urban network research. Unlike physical flows—such as aviation, rail, or maritime transport—which remain constrained by geography and capital intensity, digital information circulates with negligible friction, enabling new forms of relational proximity. This transition compels scholars to consider not only material linkages between urban nodes but also the symbolic, cognitive, and semantic connections that underpin digital visibility and influence.

2.1 Approaches to mapping urban networks in cyberspace

The rise of large internet firms, which aggregate vast geospatial datasets and user-generated content, has further catalyzed scholarly interest in mapping urban visibility and functionality online (Brunn 1998, Nunes 2006). In this regard, three primary research strands dominate the field.

The first focuses on linkage and semantic analysis. Early studies in internet geography relied on hyperlink networks to visualize intercity information flows, with the count of links between municipal or corporate websites serving as a proxy for relational strength (Devriendt et al. 2011, Huh and Kim 2003, Williams and BRUNN 2004). These studies demonstrated that online link structures often replicate global economic hierarchies. A more recent advancement is geographic text analysis, notably the toponym co-occurrence methodology (Wang et al. 2024). This semantic approach provides a valuable window into how intercity relationships are discursively constructed and perceived in cyberspace.

The second strand examines the individual activity patterns, leveraging platforms to map human mobility and spatial behaviors. Among these tools, location-based social media (LBSM) platforms, such as Weibo, mobile phones, Facebook, and Twitter, has been widely employed for its ability to combine location-sharing and social networking services, resulting in an explosion of rich, spatially referenced information on users and their activities (Doyle et al. 2014, Järv et al. 2012, Senaratne et al. 2014, Zhang et al. 2016, Sun et al. 2013). For instance, Fang et al. (2020) analyzed 500,000 Weibo posts across 13 cities in the Beijing-Tianjin-Hebei region to evaluate the strength of spatial networks in urban agglomeration. Similarly, Li and Niu (2021) employed mobile phone network data to track population flows in the Yangtze River Delta, delineating a megacity region with functional linkages in a continuous urbanized area.

The proliferation of large internet firms have catalyzed a focus on the third strand, which is to capture the cognitive interests and information demand that drive the digital “attention economy”. Search engine data (e.g., Google Trends, Baidu Index) represent a critical resource for assessing a city’s symbolic visibility and perceived influence. Unlike LBSM, which measures reactive mobility, search data captures proactive intent, the information users actively seek for making decisions on travel, investment, or housing. Studies using the Baidu Index have demonstrated a strong association between search volume and a city’s role in economic, technological, and cultural domains, suggesting search volume effectively reflects a city’s digital capital (Liu and Wang 2025, Liu et al. 2025). Furthermore, the emergence of platforms such as short-video apps highlights how cities can rapidly accumulate symbolic capital and challenge

traditional hierarchies through highly visible, viral content (Chen et al. 2024), underscoring the dynamic nature of digital attention.

2.2 Structural characteristics of urban networks in cyberspace

Research on digitally mediated urban networks reveals two structural characteristics reshaping intercity relations. First, flows in cyberspace contribute to new patterns of hierarchical differentiation. In the digital realm, a city's influence increasingly derives from symbolic capital—such as visibility, reputation, and social media attention—rather than solely from economic scale. Cities with higher digital search volumes or higher levels of online attention tend to play more central roles in economic and technological systems (Wang and Loo 2019). Although peripheral cities occasionally gain temporary prominence through viral content, such effects are often volatile, unstable, and dependent on continuous platform amplification (Zhang et al. 2026). Core cities remain dominant in information production, consistent with long-standing observations in world city and digital geography literature (Mitchelson and Wheeler 1994, Fang et al. 2024a). This suggests that digital information flows have not fully democratized visibility. Rather, they reproduce and sometimes intensify existing spatial inequalities.

A second major finding is that informational flows facilitate deepening regional integration. Cross-platform data—including online searches, mobile phone records, and LBSM activity—show that information-based linkages strengthen cross-city coordination within major urban clusters such as the Beijing–Tianjin–Hebei region, Yangtze River Delta, and Pearl River Delta (Yang et al. 2024). ICTs accelerate knowledge diffusion (Tranos 2020), enhance learning and innovation spillovers, and help form “virtual proximity” that complements physical interactions. This proved that flows in cyberspace are now a primary driver of spatial integration and networked urban development.

2.3 Summary

Although existing studies have substantially advanced our understanding of urban networks in cyberspace, they still exhibit limitations, particularly regarding the temporal evolution of digital intercity linkages. Few studies adopt a nationwide, multi-year perspective to systematically map how urban networks are restructured in cyberspace, highlighting the need for a comprehensive, longitudinal, national-scale examination. To address this gap, this analysis constructs yearly information-flow networks for Chinese cities from 2012 to 2019, enabling a systematic assessment of both the structural configuration and the evolutionary trajectory of China's urban system in cyberspace. Notably, the Baidu Index captures asymmetrical online search behaviors, providing

new insights into digital hierarchy, and symbolic prominence.

3. Methodology

3.1 Data source

In the context of an increasingly digitized society, web search behavior offers a critical lens through which to observe how individuals and institutions perceive, prioritize, and engage with cities. The Internet, functioning as an exploratory interface, allows users to actively seek information on unfamiliar urban environments, rendering search data a meaningful proxy for symbolic attention and digital connectivity (Terlouw and Denkers 2011, Long et al. 2011). Among available tools, the Baidu Index stands out for its extensive coverage, methodological transparency, and strong representativeness within China's digital ecosystem (Huang et al. 2017, Li et al. 2018, Vaughan and Chen 2015). This study leverages Baidu Index data as the foundation for constructing intercity attention networks, for three key reasons. (1) The Baidu Index captures relationships between economic, transport, and digital spaces, providing a holistic view of urban networks. Its vast data volume enables a detailed examination of the interconnectedness between cities, making it an ideal resource for studying urban network structures. (2) Baidu is dominance as China's primary search engine, driven by the government's strict Internet censorship policies (Liebelson 2014), ensures that the data collected reflects a broad and representative sample of online behavior. With over 900 million active users, Baidu provides extensive search data that offers reliable insights into public interest and urban interactions. (3) The Baidu Index contains both geographical information and a range of social attributes associated with web search activities, allowing researchers to examine various socio-spatial correlations such as business interactions, leisure activities, residential patterns, and employment trends. By leveraging these attributes, the Baidu Index serves as a robust data source for analyzing the interconnectedness of China's urban cyberspace.

3.2 Network generation

The specific steps for data collection and network construction are as follows. Data for this analysis were collected from the Baidu Index platform (<https://index.baidu.com/>), with edges representing the average daily search volume between any two cities. In particular, the Baidu index identifies information by recording keywords that are relevant to a certain city, for instance, Beijing. When Internet users in Beijing search keywords as "place + what they are seeking information on" (e.g., Shanghai travel, Shanghai business, or Shanghai hotel), the city-related information thus generated is recorded and combined as the Baidu index. Thus, by including the city name in the

keyword, we can obtain the edge from Beijing to Shanghai (Fig.1). Conversely, when Internet users in Shanghai search for information using “place + what they are seeking information on” (e.g., Beijing travel, Beijing business, or Beijing hotel), the generated information is recorded and identified as the edge from Shanghai to Beijing. This approach captures the flow of information and interest between cities, reflecting underlying socio-economic interactions and enabling the construction of a directed network. To ensure temporal consistency and mitigate the influence of short-term fluctuations or sudden spikes caused by specific events, we aggregated all city-related search terms to the annual scale. We used standardized city names as the core search keyword anchors to ensure semantic stability across time. We acknowledge that Baidu Index data may contain inherent limitations and potential biases, such as uneven internet penetration across regions, demographic differences in search behavior, and regional disparities in digital infrastructure. While these factors are difficult to eliminate entirely, we emphasize long-term patterns over short-term anomalies. These strategies help ensure greater stability and representativeness in the resulting data.

Figure 1. Generation of intercity network.

The analysis spans the period from 2012 to 2019 to capture the dynamic evolution of China’s cyberspace. The rationale for selecting this timeframe is as follows: Although Baidu platform data is available from 2011, the dataset for that year is incomplete, with records for certain cities missing. Upon thorough evaluation, 2012 was determined to be the year with the most complete data. Additionally, 2012 marks a pivotal period in China’s urbanization and the expansion of its communication infrastructure (Chen et al. 2019). Furthermore, the year 2020 saw the onset of the global COVID-19 pandemic, which profoundly impacted societal and economic activities. To mitigate the potential distortions introduced by such a major event, this analysis focuses on the period from 2012 to 2019, thereby ensuring the reliability and consistency of the analysis.

The study focuses on 296 prefecture-level cities and above for the year 2019, as these cities represent the core of China’s urban network (Fig.2). These cities account for the majority of China’s urban population and economic output, serving as regional hubs for economic, cultural, and social activities, making them essential for studying urban cyberspace dynamics. Furthermore, these cities generally possess well-developed digital infrastructure and higher levels of Internet penetration, ensuring that search behavior data are representative of broader trends in online interactions. As a result, a directed network is constructed, represented by a directed matrix with $(296 * 296) - 296 = 87320$ directed edges, where each edge reflects the search-based connection between two cities.

Figure 2. Selected cities.

3.3 Indicators of network analysis

By constructing a weighted network, we explored the direction and strength of the connection between cities. This analysis adopted a directed weighted network, which can reasonably evaluate the spatial structure characteristics of urban networks in cyberspace.

(1) Out-in flow

The out-in flow was calculated based on outflow and inflow. Following (You et al. 2023), the outflow is defined as follows:

$$O_i = \sum_{i \neq j}^n S_{ij} \quad (1)$$

where S_{ij} refers to city i 's volume of the Baidu index searched by city j , and O_i refers to the total volume of the Baidu index of city i searched by other cities. The inflow is defined as follows:

$$I_i = \sum_{i \neq j}^n S'_{ij} \quad (2)$$

where S'_{ij} refers to the Baidu index of city i searched for city j , and I_i refers to the total volume of the Baidu index of city i searched for other cities.

Subsequently, we compared the outflow and inflow, which we have referred to as the out-in flow.

$$Out - in flow_i = O_i - I_i$$

Two results were achieved, which are as follows: (1) $Out - in flow_i > 0$, which indicates that city i has more outflow than inflow, further indicating that it is being searched more than when compared with how much it searches for other cities. (2) $Out - in flow_i < 0$, which indicates that city i has more inflow than outflow, further indicating that it searches for other cities more than how much it is searched by other cities.

(2) Strength

The strength of city i refers to the total volume of outflow and inflow.

$$S_i = O_i + I_i \quad (3)$$

(3) Maximum linkage

Maximum linkage refers to the largest linkage between a city and its connected cities; it is defined as follows (Wu et al. 2018):

$$Max_i = Maximum (S_{ij}, i \neq j, j = 1,2,3, \dots n) \quad (4)$$

4. Results

4.1 Analysis of cities

4.1.1 Ranking cities in cyberspace

The ranking of cities in cyberspace should be regarded as indicative of the hierarchical positions of these cities within the digital space. Although any discussion concerning an urban hierarchy may be unfashionable, examining cities from the perspective of their urban ranking makes sense. The ranking of cities in cyberspace was conducted over the period 2012–2019. Our results reveal the evolution of cities' positions in web search activity (Fig.3). The first point to make here is that the primary cities (i.e., Beijing and Shanghai) were the two leading cities during 2012–2019. Specifically, the total volume of Baidu index for Beijing and Shanghai accounted for more than 1.4% of the overall search volume. This indicates that Beijing and Shanghai hold dominant positions in cyberspace due to their significant population and economic potential, with Beijing being the national capital and Shanghai serving as a key regional hub, respectively. Second, some cities, such as Chengdu, Hangzhou, Wuhan, and Qingdao, have risen considerably in their ranking. These cities have unique city labels and national policy inclinations to attract people from other cities to search, which make them moved from lower to higher positions in terms of web search activity, indicating a rise in their prominence in cyberspace. Third, cities, such as Chongqing, Xi'an, Wenzhou, and Baoding, have experienced a decline in their rankings, moving from higher to lower positions in the same period. This suggests a relative decrease in their visibility and search activity compared to other cities. Chongqing and Xi'an rank among the top in terms of population size and economic development level, and their ranking decline is mainly affected by the crowding-out effect of the latecomers. However, cities such as Wenzhou and Baoding do not have a large population scale and economic development level, and they have not been tilted by the focus of national policies in recent years, so their attention has shown a downward trend.

These divergent trajectories reveal that digital visibility is not solely a direct function of population size or GDP, but also increasingly tied to a city's ability to cultivate symbolic assets, cultural capital across digital platforms. Cities that combine economic functions with effective media strategies, cultural branding, and platform integration are more likely to ascend in the digital hierarchy. Conversely, those cities that rely solely on economic connections without shaping city visibility declining their rankings in cyberspace.

Figure 3. Ranking trajectories of major Chinese cities in cyberspace (2012 – 2019).

4.1.2 Out-in flow

The analysis of out-in flow indicates an imbalance between cities' inward and outward flows. Three key observations can be made from data presented in Fig.4, which shows outflow, inflow, and out-in flow in 2019. These observations are as follows: (1) Cities in Eastern China exhibit the maximum acceleration in terms of outflow. As illustrated in Fig.4a, the majority of cities with significant outflow are distributed in Eastern China, particularly in the Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing sub-regions. This trend reflects the high search volume directed towards other cities from these regions, consistent with their advanced population and economic development. These areas are both highly developed and densely populated. (2) Regarding inflow (Fig.4b), the high-value areas are unsurprisingly concentrated in the Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing regions. This shows that these regions are increasingly popular, attracting significant search interest from other cities. (3) In the out-in flow, presented in Fig.4c, some cities can be seen to have more outflow and less inflow, indicating that they search more than being searched by other cities. These cities include Beijing, Nanjing, Zhengzhou, and Wenzhou, to name a few, most of which are distributed in eastern China. By contrast, some cities have more inflow and less outflow, indicating that they are being searched more than how much they search for other cities. These cities include Urumqi, Tianshui, Shigatse, and Hanzhong, among others, and most of them are in western and middle China. However, some exceptions in this regard are Chengdu and Changsha, which have more outward flows. These cities have more inflow because of their role as tourist hotspots. They have been widely known for their natural beauty, often chosen as a holiday destination by individuals, families, and tour groups. This helps explain why they are net-outflow cities in cyberspace.

Collectively, the east-west disparity in out-in flow is not merely a reflection of economic imbalance. Instead, it underscores the differentiated symbolic roles that cities play in China's digital urban system. Eastern cities, with their institutional power, economic dominance, and dense digital infrastructure, act as information hubs that shape national discourse. Cities in Western China, while less developed, often gain visibility through cultural branding, tourism narratives, or policy initiatives.

Figure 4. (a) Nodes' outflow (b) Nodes' inflow (c) Nodes' out-in flows in 2019.

4.2 Analysis of intercity linkages

4.2.1 Flow change

Using ArcGIS network analysis platform, the topological relationships were converted into spatial connections, thereby constructing cyberspace networks based on the web search activity (Fig.5). The evolution of these networks can be divided into the following three stages: (1) The first stage, which pertained to the period 2012–2013, presented a radial model with Beijing and Shanghai as the centers. The eastern coastal cities of China emerged as the core areas of the cyberspace network during this stage. (2) The second stage, which pertained to the period 2014–2016, presented denser connections, especially among cities in the eastern region. More urban agglomerations became central nodes, including the Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing regions. By 2016, a triangle structure emerged, with Beijing-Tianjin-Hebei, Yangtze River Delta, and Chengdu-Chongqing forming the vertices, while the connections between adjacent regions formed the boundaries. The triangle structure held a large number of connections. (3) In the third stage (2017–2019), a diamond structure emerged, with the four core areas of the Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing regions serving as the vertices. The connecting lines between adjacent regions formed the the boundaries of structure. By 2019, the cyberspace network reflected this diamond configuration, with Beijing, Shanghai, Chengdu, and Shenzhen as the key cities at the vertices, and their connections with surrounding regions forming the sides.

Figure 5. Baidu index layout in 2012–2019.

4.2.2 Maximum linkages

Maximum linkage refers to the strongest connections between city pairs, which constitutes the backbone network in cyberspace. Two key observations can be made by studying Fig.6, which are as follows. (1) Maximum linkages are largely constrained by provincial boundaries, creating relatively closed and independent geographical systems in space. In particular, Chengdu had 19 maximum linkages in 2019, followed by Harbin and Xi'an, each with 13. Most of these linkages occur between provincial capitals and cities within the same province. (2) There are relatively few maximum linkages between provincial capitals. Consequently, the most urbanized and economically developed cities, such as Beijing and Shanghai, have fewer maximum linkages.

Figure 6. The maximum linkage.

4.3 Distance decay and concentration

The relationship between geographical proximity and web search activity, and how the relationship changes over time, is explored in this section. This section examines the extent to which cyberspace flow can overcome geographical constraints. To investigate this, we considered geographical distances when establishing connections between cities. Our analysis revealed three distinct intervals with observable trends (Fig.7). In the first interval of 0–400 km, the proportion of web search activity to the total volume of the Baidu index for a city was approximately 6%. In the second interval of 400–1200 km, the web search activity remained at a high volume. Subsequently, in the third interval of 1200–4200 km, there was a significant drop in web search activity as the distance increased. In sum, the largest web search activity for cities occurred within a distance of 200–1,200 km, accounting for 61.7% of total web search activity. Conversely, the least amount of inter-city web search activity occurred within the distance of 3,600–4,200 km, with an accumulation proportion of 1% of the overall web search activity. The distribution curve of the Baidu index reflects a spatial relationship between web search activity and distance, demonstrating the attenuation law of passenger flow in cyberspace.

Figure 7. Distance distributions of the web search activity networks in 2019.

Fig.8 presents the distribution of the Baidu index by city pairs. Two key observations can be made in this regard. (1) The volume of the Baidu index was primarily concentrated among a small subset of city pairs. For example, approximately 60% of the web search activity was concentrated in 20% of the node pairs, while 80% of the web search activity was concentrated in 34% of the node pairs. (2) The network underwent continuous adjustment, wherein web search activity weakened between certain cities from 2013 to 2019. For instance, Specifically, 20% of the city pairs accounted for 60% of the web search volume in 2013, but by 2019, this proportion had decreased to 56.8%.

Figure 8. Distribution of the Baidu index by city pairs in China.

5. Discussion

The results of this analysis reveal several important insights regarding the structure and dynamics of urban networks in cyberspace.

5.1 Spatial agglomeration in cyberspace

The urban network constructed based on web search activity shows an uneven spatial distribution, with links between cities not being equivalent, as predicted by urban network theory

(Wall and Van der Knaap 2011). Particularly, since 2016, the spatial distribution gradually displayed a quadrilateral pattern, formed by the four core regions of Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, and Chengdu-Chongqing as the vertices. As demonstrated by previous studies, China's economic development pattern and population flow presented a diamond structure with the same four core regions as the vertices (Fan et al. 2019, Zhang et al. 2020a). Thus, cities with higher levels of economic development and larger population was expected to be popular among Internet users, indicating that trends in cyberspace are largely shaped by development patterns.

Second, these findings highlight that symbolic visibility in cyberspace is associated with more than population size or GDP. It is related to a complex interplay of media exposure, cultural assets, governance orientation dynamics. Despite the borderless potential of cyberspace, traditional spatial structures, such as provincial boundaries, geographical distance, and territorial policy divisions, continue to exert a significant influence on the distribution of digital flows. In particular, the radiation range of intercity connections often remains confined within provincial borders, giving rise to fragmented sub-networks embedded in local administrative units. Although the internet substantially reduces the friction of distance in terms of information dissemination, empirical evidence suggests that information-seeking behavior remains strongly correlated with spatial proximity (Zhang et al., 2017). This apparent paradox, the persistence of proximity in a space designed to transcend it, underscores the enduring role of territorial structures in shaping digital interaction (Ash et al. 2018). Moreover, national policy orientation continues to structure digital attention hierarchies (Chen et al. 2016). For instance, the emergence of the four major clusters, such as Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing, closely aligns with "the National New Urbanization Plan (2014–2020)", etc.. This policy orientation may accelerate the formation of tightly interconnected sub-networks within each region, reflected in the increasing modularity and clustering in cyberspace flows. Taken together, these observations underscore that Chinese urban network in cyberspace is not a purely emergent or bottom-up structure. Rather, it reflects an institutionally co-produced spatial order, where user behavior interacts with planning interventions, policy branding, and infrastructure development to generate a hybrid configuration of digital connectivity.

5.2 Localized restructuring of urban hierarchies

Intercity information flows based on search intent are inherently asymmetric, distinguishing them from traditional transportation flows. The outflow of web search activity exhibits obvious spatial agglomeration characteristics, demonstrating that the web search activity demand in China is geographically unbalanced. Specifically, Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, and Chengdu-Chongqing regions occur at the core of the network with a highly

notable influence, and they exhibit a high concentration of web search activity due to their economic and demographic advantages. In contrast, the inflow does not exhibit obvious characteristics in regard to spatial agglomeration, indicating that the internet attention resources are scattered, but cities such as Chengdu, Xi'an, Chongqing, Shanghai, Nanjing, Shenzhen, Beijing still benefit from significant economic and population advantages.

These asymmetries in digital attention have facilitated the localized restructuring of urban hierarchies, as some cities gain additional visibility through network concentration or media effects. The emergence of "internet celebrity cities" illustrates how social media factors can reprogramming of urban hierarchy in cyberspace. The affordances of digital platforms enable alternative pathways for ranking ascent, allowing some cities to break away from the constraints of physical hierarchies. Cities that proactively craft cultural narratives, integrate with platform logics, and align with media ecosystems have succeeded in enhancing their visibility and influence. Zibo, for instance, a relatively small and economically peripheral city, experienced a viral surge in digital attention through its local barbecue culture (Zou et al. 2025). In contrast, some other cities, even though they are transport central and economically significant, have not translated its material prominence into sustained influence in cyberspace. This indicates that while structural factors such as GDP, population, proximity and administrative status remain influential, media virality, symbolic capital increasingly determine a city's digital prominence, highlighting the transformative potential of digital platforms in redefining urban networks, particularly at regional and local scales (Chen et al. 2024). This shift points to a reprogramming of urban hierarchies in the attention economy, where cities compete not only for capital and talent, but also for clicks, visibility, and cultural relevance.

5.3 Organizational models in cyberspace

The fourth point worth mentioning concerns the emergence of an organization model in cyberspace. In sum, the national network in cyberspace exhibited an organization model that radiated from multiple central cities. This organizational model was determined by different levels of economic development and the various administrative levels. Therefore, the general connection model, as illustrated in Fig.9, can be summarized as follows. (1) Connections were primarily concentrated among provincial capital cities and intra-provincial urban clusters. Due to limitations imposed by distance decay and administrative boundaries, inter-provincial linkages were relatively weak. Most peripheral cities established vertical connections with nearby core cities (e.g., provincial capitals), resulting in a radial and hierarchical structure dominated by mega-

cities such as Beijing and Shanghai. This stage exhibits strong disassortative mixing, where less visible cities preferentially connect to highly prominent ones. This is also observed in transport networks (Zhang et al., 2019), and serves as a mechanism through which core cities expand their symbolic hinterlands. At this stage, cyberspace flows mirror traditional physical networks, particularly rail or air systems, with a high degree of centralization and asymmetry. (2) In the second stage, a triangular network morphology began to take shape. This phase was marked by the growing dominance of China's most urbanized cities—such as Beijing and Shanghai, which continued to assert their influence in cyberspace through large populations, robust economies, and digital activity. A defining feature of this stage was the rise of assortativity, referring to a tendency for cities with similar economic and administrative status to form horizontal, bidirectional connections. These connections were often shaped by geographical proximity and regional governance structures, resulting in the emergence of regionally clustered digital hubs. This stage signaled a partial erosion of the previous mono-centric hierarchy, as regional digital centers gained symbolic and structural prominence. Notably, unlike the gradual, infrastructure-led changes in physical networks, while spatial proximity continued to influence connection patterns, digital ties became more fluid and less constrained by geography. Overall, this period marked a gradual transition toward a more balanced, horizontally integrated digital landscape, where cities of comparable standing interacted more intensively, reinforcing the trend of increasing assortativity. (3) As the digital urban network continued to evolve, it entered a stage characterized by the formation of a relatively stable diamond-shaped spatial configuration. In this pattern, multiple regional poles collectively supported the structure of the national cyberspace, indicating a transition from a centralized system to a multi-core, interlinked network. This phase was marked by increasingly intensive interregional linkages and enhanced internal cohesion within regional clusters, reflecting a structural consolidation of distributed symbolic power.

Figure 9. Main organization model of network structure in cyberspace.

5.4 Geographic constraints in cyberspace

Although drawing a comparison between cyberspace and physical networks was not one of the aims of our analysis, this analysis the results reveal both similarities and differences when juxtaposed with traditional, transport-based methods. In terms of similarities, relative rankings of city connections coincide broadly with recognized urban networks (Fang et al., 2020), and geographical proximity continues to exert a strong influence (Hu et al. 2025, Wen et al. 2025). Nevertheless, the urban network in cyberspace diverges considerably from networks generated by

transport links (Yang et al., 2019), indicating advances in information technology may reshape regional disparities. (1) While geographical distance exerts a great impact on cyberspace flows, its effects differ from those observed in transport networks. Overall, cyberspace flows are less spatially concentrated yet still follow a distance decay principle. Specifically, 80% of the total volume of web search activity is concentrated within 0–1500 km. In comparison, 80% of train flows occur within 0–700 km, while 80% of air passenger flows occur within 0–1500 km (Wang et al. 2020). (2) Although provincial boundaries affect both cyberspace and transport networks, they appear more pronounced in cyberspace. In cyberspace networks, provincial capitals primarily maintain their strongest linkages within their own provinces. By contrast, in aviation networks, these capitals typically connect to key national hubs such as Beijing, Shanghai, Guangzhou, and Urumqi, thereby diminishing the influence of provincial borders.

In sum, the Internet has undergone rapid development, and web search activities have seen a rise in recent years, which provides the basis for our initial analysis. While this study provides a comprehensive visualization and interpretation of the evolving spatial structure of Chinese urban networks in cyberspace, future research should seek to expand its analytical scope in two important directions. One key limitation of this analysis is its reliance on Baidu Index data from the pre-pandemic period (2012–2019). We acknowledge that the digital landscape has undergone significant shifts in the post-COVID era, including the rise of new content ecosystems such as short video platforms (e.g., Douyin, Xiaohongshu). Future research could extend this work by incorporating post-2020 data to examine how urban digital networks have reconfigured in response to changing media logics, evolving platform infrastructures, and shifting user behavior patterns. Such analysis would provide a more comprehensive understanding of how cities adapt their digital strategies and identities in an increasingly fragmented, multi-platform environment. The second limitation is the vulnerability of web search activity to unexpected events, such as public health crises, natural disasters, or viral trends, which can cause abrupt fluctuations and potentially distort the observed network structures. Eliminating the impact of these emergencies on web search volume will facilitate a more accurate construction of network structures in cyberspace. Despite the aforementioned limitations, this analysis has taken the first step toward understanding some of these issues, and it outlines the characteristics of cyberspace, thereby complementing the existing cyberspace studies. Future research could address these concerns by integrating multiple data sources, adopting anomaly-detection methods, and collecting data over longer periods to enhance the validity and robustness of cyberspace network analyses.

6. Conclusion

This analysis explored the structural characteristics and temporal evolution of urban networks by analyzing web search activity, thereby offering an alternative perspective on cities' roles in cyberspace. Due to limited data availability, studies on urban networks in cyberspace have tended to turn a blind eye to the temporal changes in the hierarchy of cities. With the application of the Baidu index, our analysis highlighted the following findings: (1) The spatial distribution of web search activity is characterized by a diamond-shaped pattern, with Beijing-Tianjin-Hebei, the Yangtze River Delta, the Pearl River Delta, and Chengdu-Chongqing serving as the primary vertices. Eastern China, which is the most urbanized and economically developed region, is home to the most prominent cities in terms of web search activity. These cities are not only active in seeking information about other cities but also attract the highest levels of inbound search attention. (2) The network structure in cyberspace is strongly associated with traditional factors such as population size, economic capacity, and geographical proximity, while distance and provincial boundaries also remain significant determinants. (3) Cyberspace offers new avenues for peripheral cities to enhance their online visibility, thereby partially reshaping local or sub-regional networks. This is particularly evident in cities like Chengdu and Urumqi, which have capitalized on their cultural and digital assets to boost their online presence and improve their positions within the urban network.

From a methodological viewpoint, the dataset gained from the Baidu platform offers rich high-volume information and provides scholars with a new approach to exploring urban networks. From a theoretical viewpoint, this analysis contributes to urban network studies by visualizing cities in cyberspace, bridging the gap between traditional urban network theory and the digital interactions that shape contemporary urban environments. From a practical perspective, flows in cyberspace should be an essential factor to consider in urban spatial planning and regional development strategies. This analysis reaffirms that a city's position in cyberspace can have tangible economic and social benefits (Loo 2004). Local authorities could capitalize on media coverage or cultural events to boost their "cyberspace presence", potentially stimulating trade, tourism, and human resource inflows. By strategically enhancing the online presence of less-developed regions (e.g., middle-western cities in China), local governments can redirect a portion of the digital attention that typically flows to more developed eastern areas. This targeted approach, which involves celebrity involvement and bolstered digital visibility, will help these cities attract new tourism and investment, draw in talent, and ultimately drive economic growth while fostering more balanced regional development.

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Figure legends

Figure 1. Generation of intercity network.

Figure 2. Selected cities.

Figure 3. Ranking trajectories of major Chinese cities in cyberspace (2012 – 2019).

Figure 4. (a) Nodes' outflow (b) Nodes' inflow (c) Nodes' out-in flows in 2019.

Figure 5. Baidu index layout in 2012–2019.

Figure 6. The maximum linkage.

Figure 7. Distance distributions of the web search activity networks in 2019.

Figure 8. Distribution of the Baidu index by city pairs in China.

Figure 9. Main organization model of network structure in cyberspace.

Data availability

The dataset generated during and analyzed during the study is attached as a supplementary file.

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Competing interests

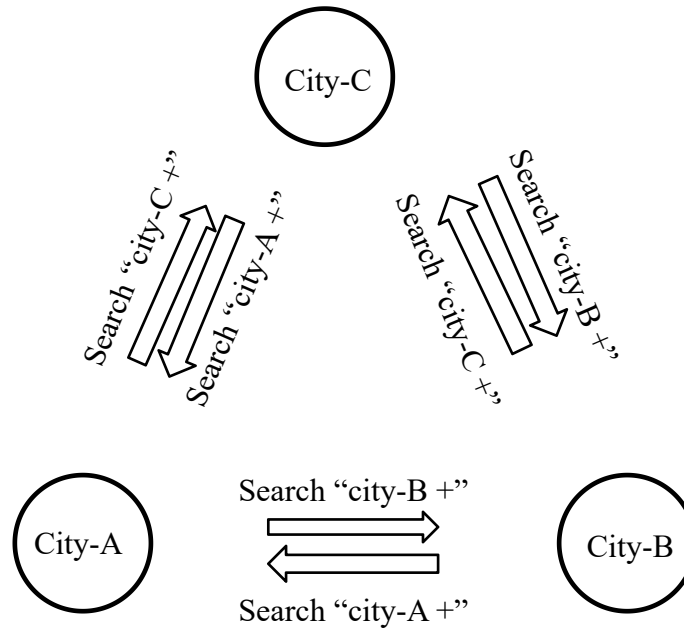
The authors declare no competing interests.

Ethical Approval

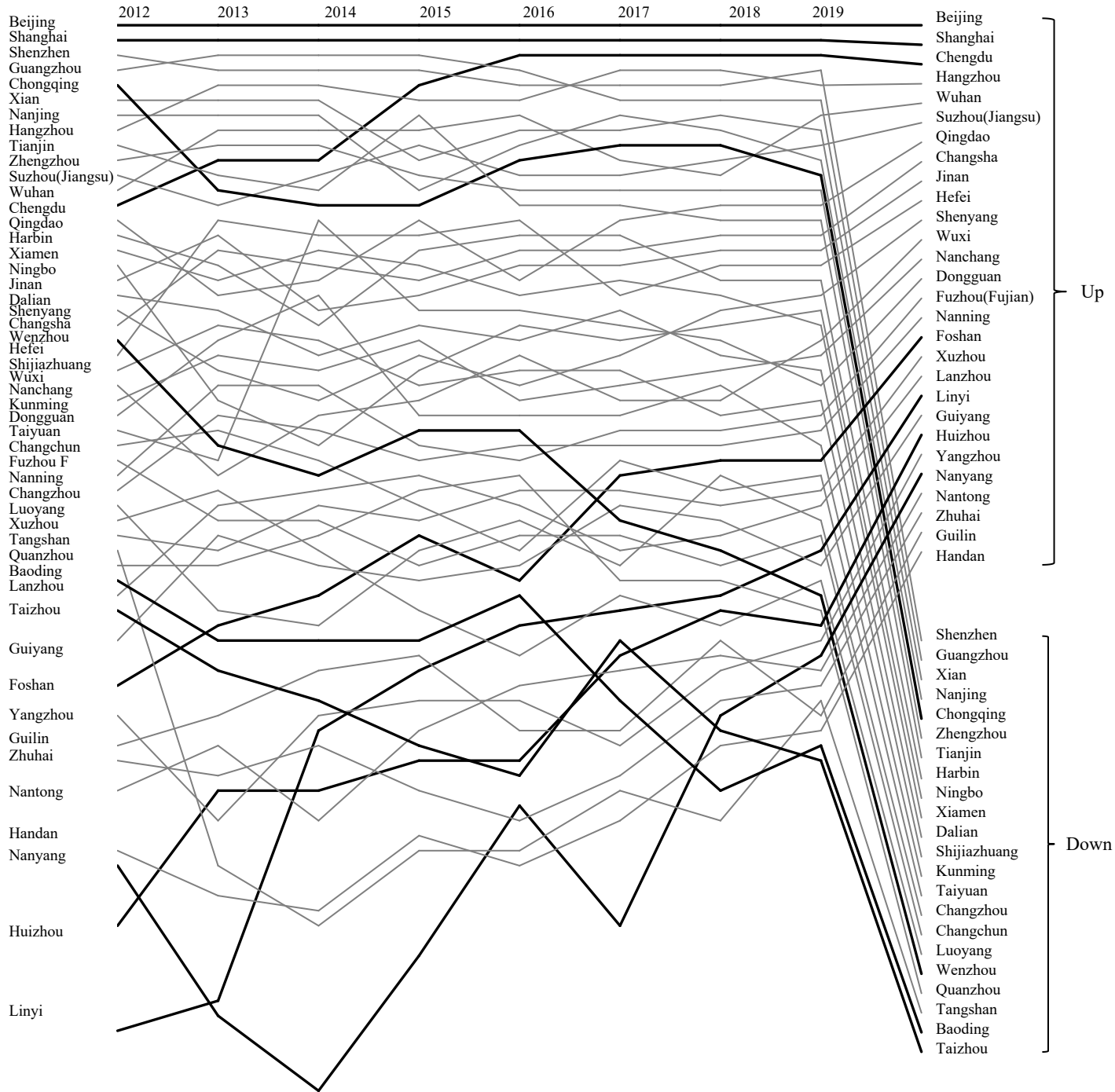
This article does not contain any studies with human participants performed by any of the authors.

Informed Consent

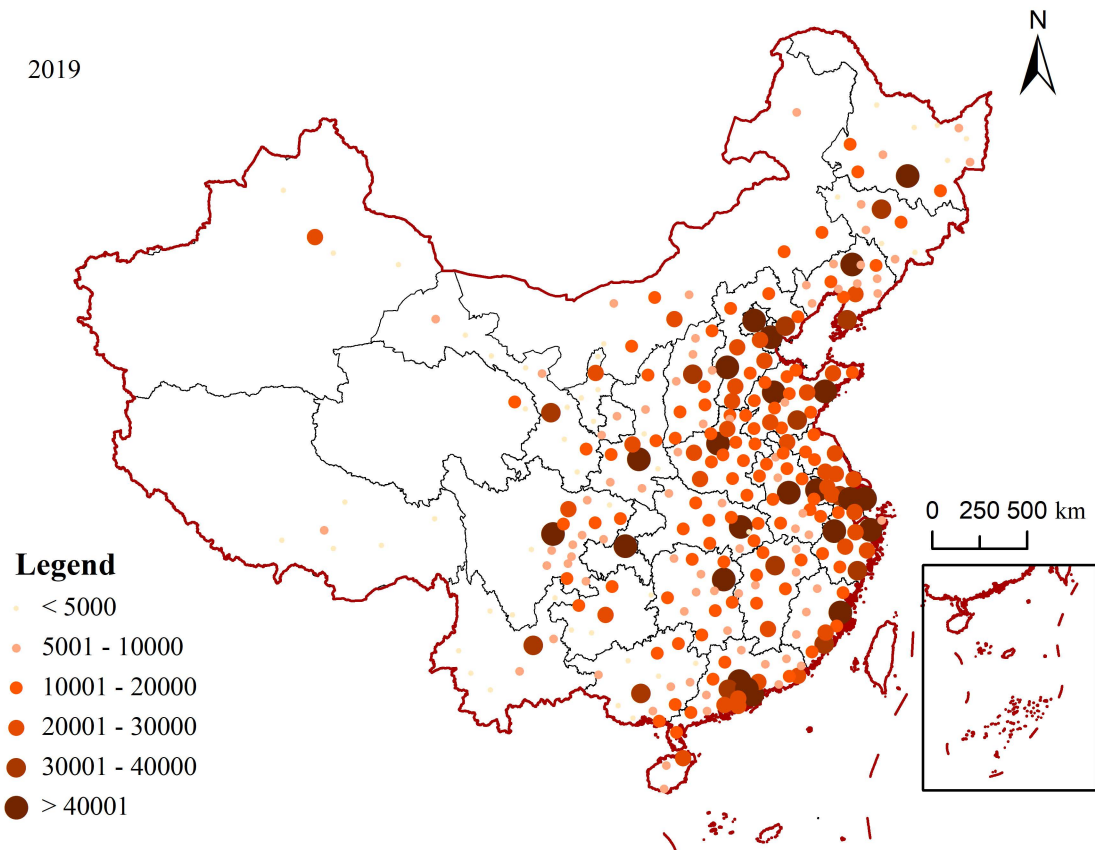
This was not required, as outlined in the ethical statement.



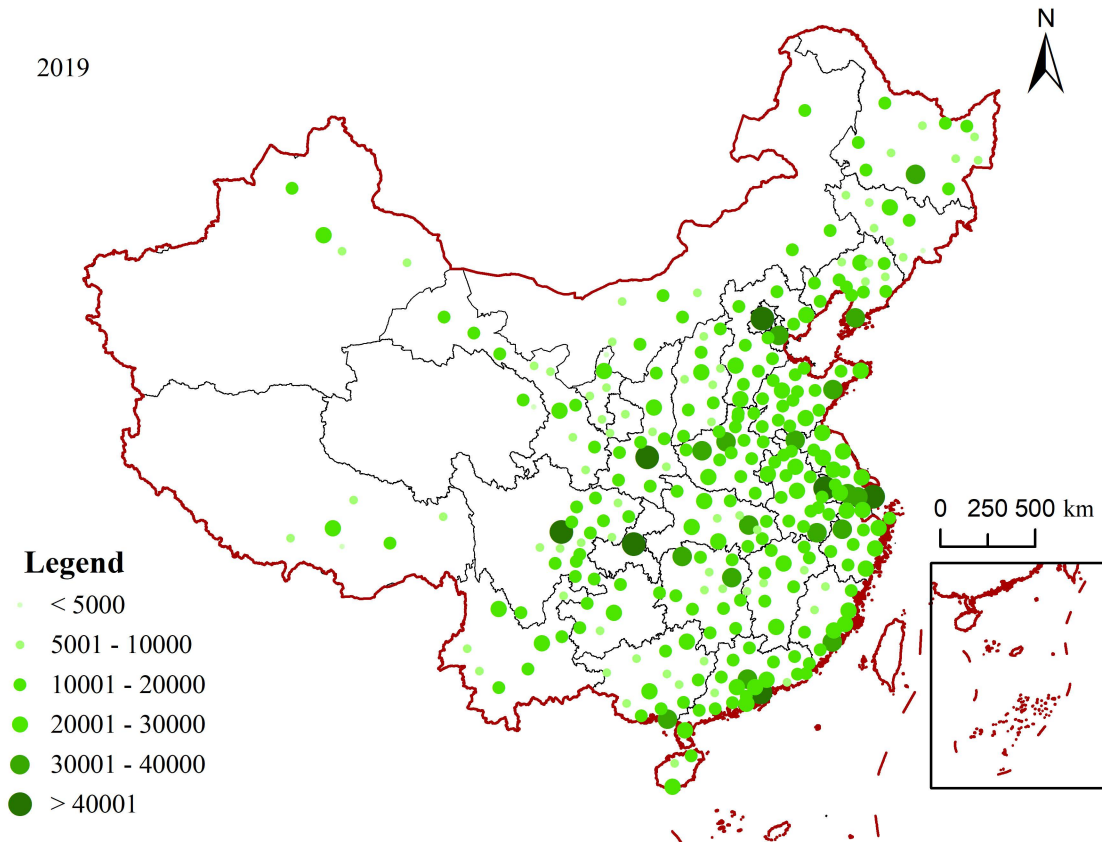




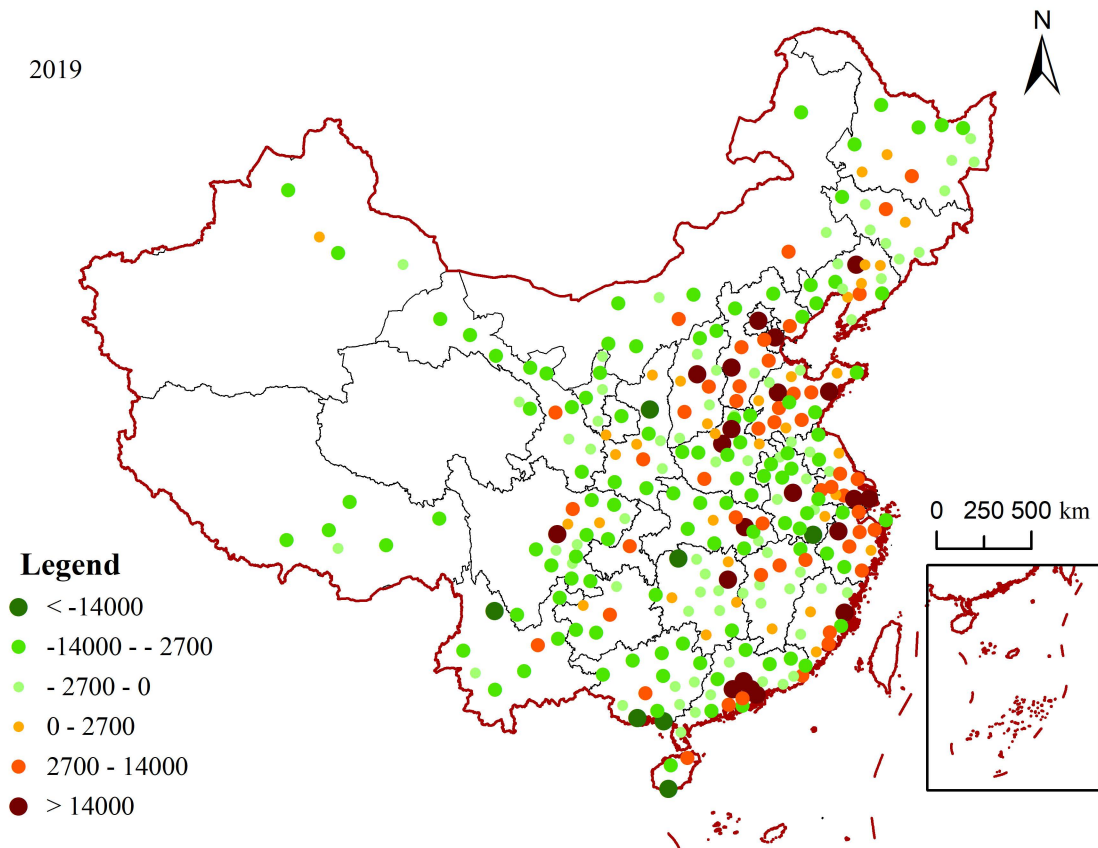
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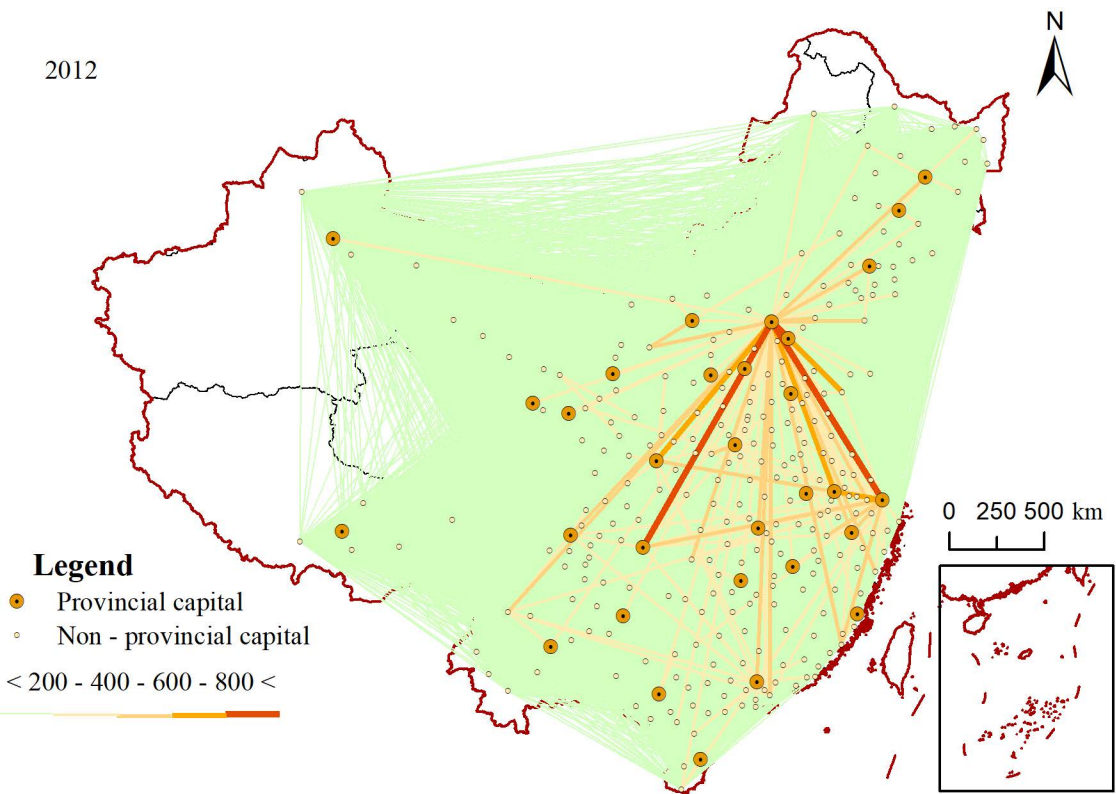
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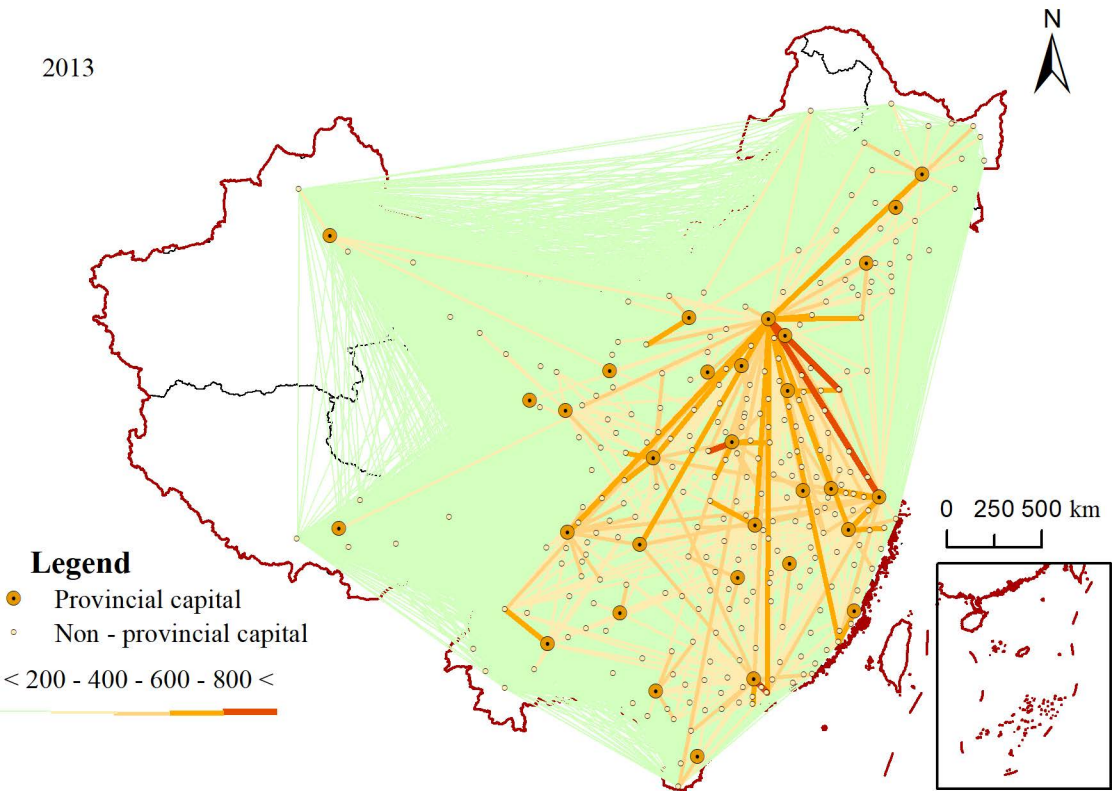
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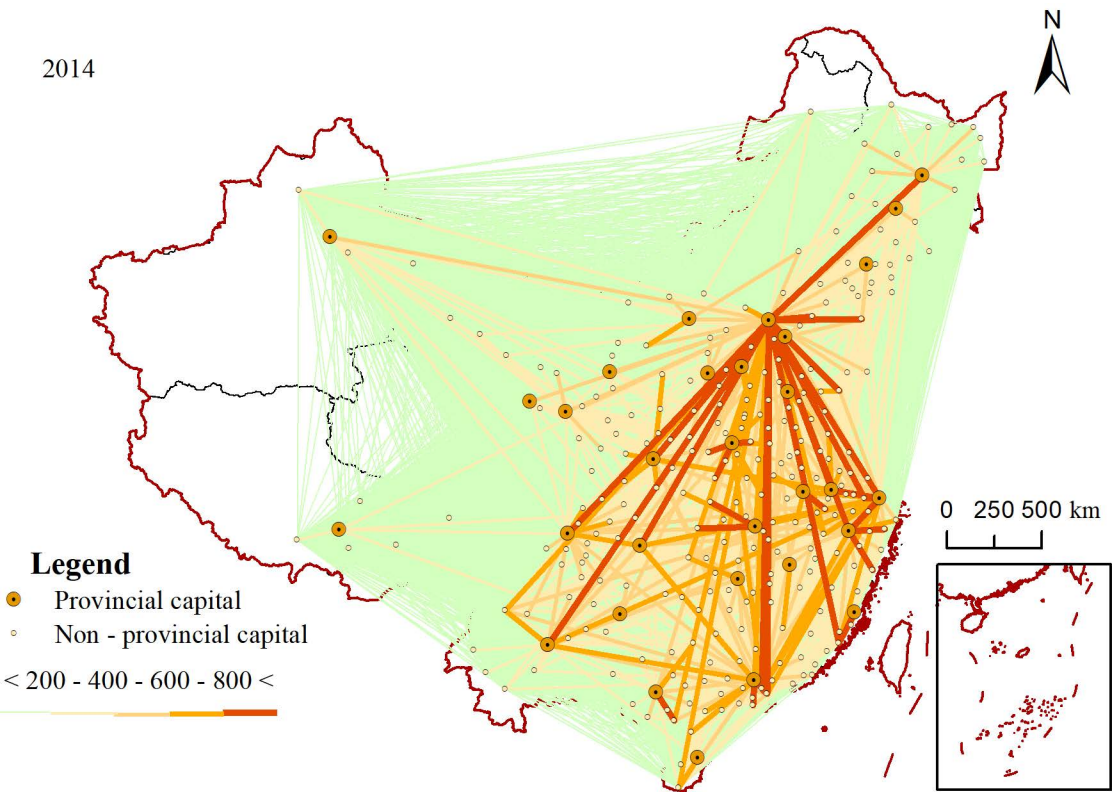
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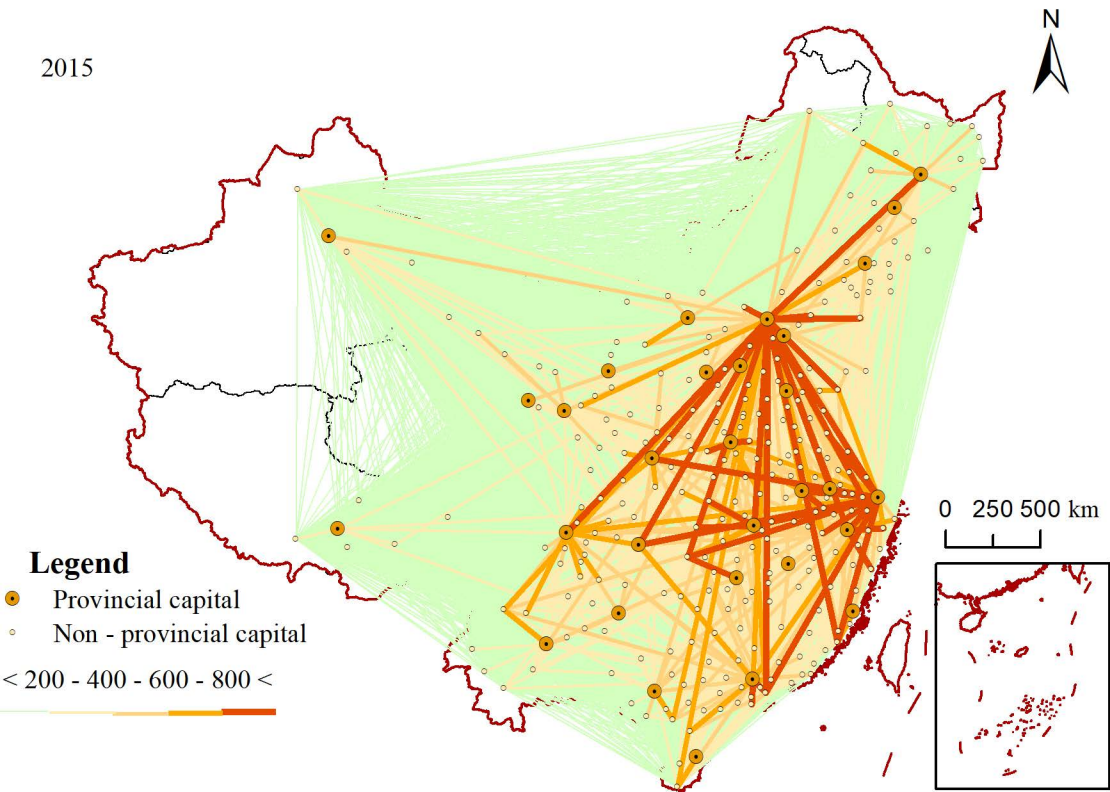
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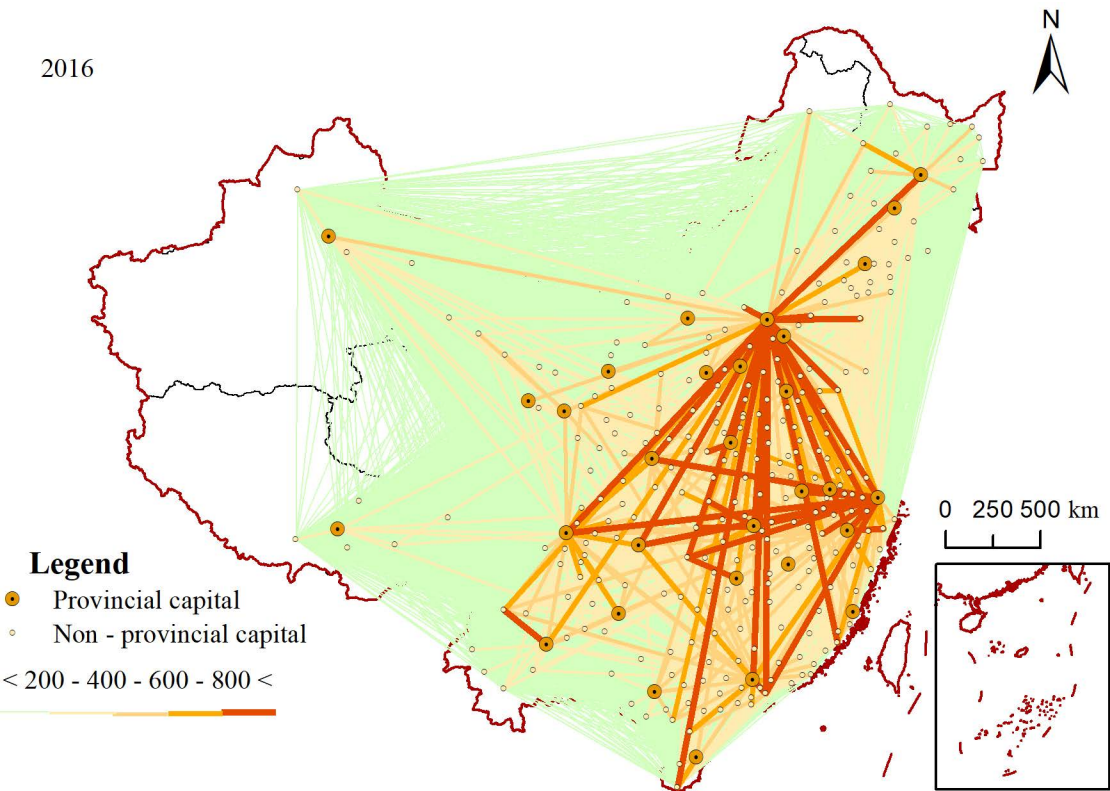
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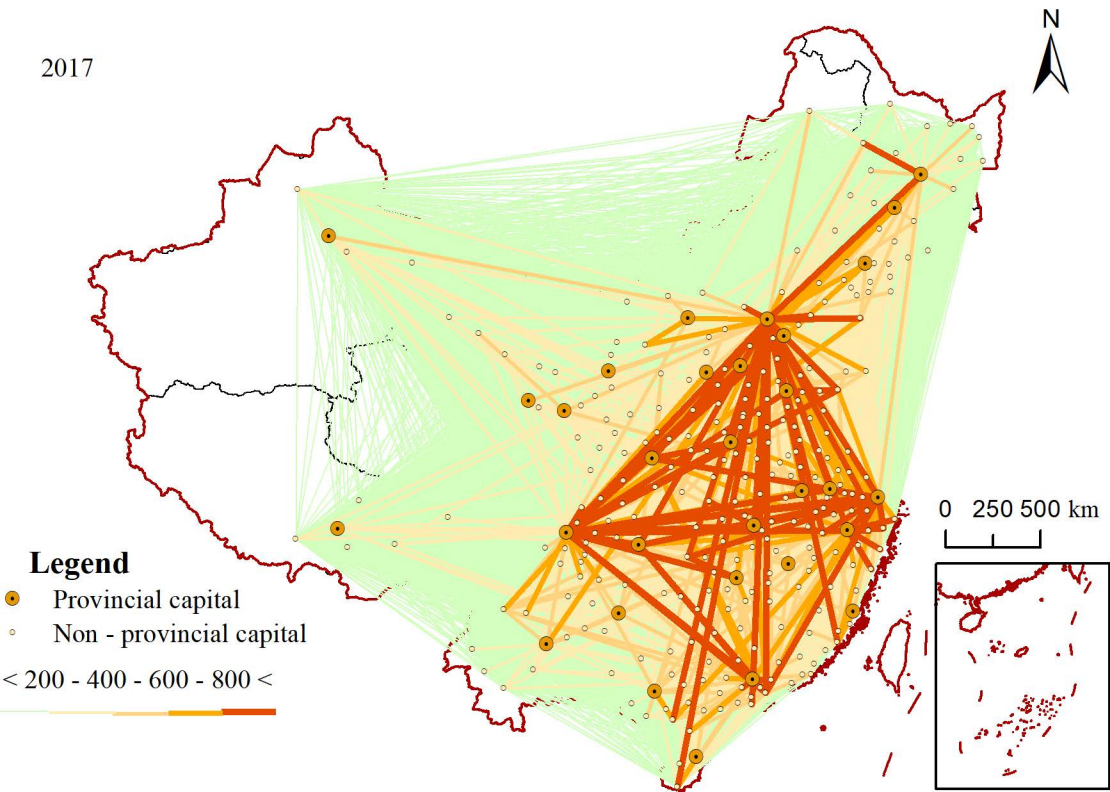
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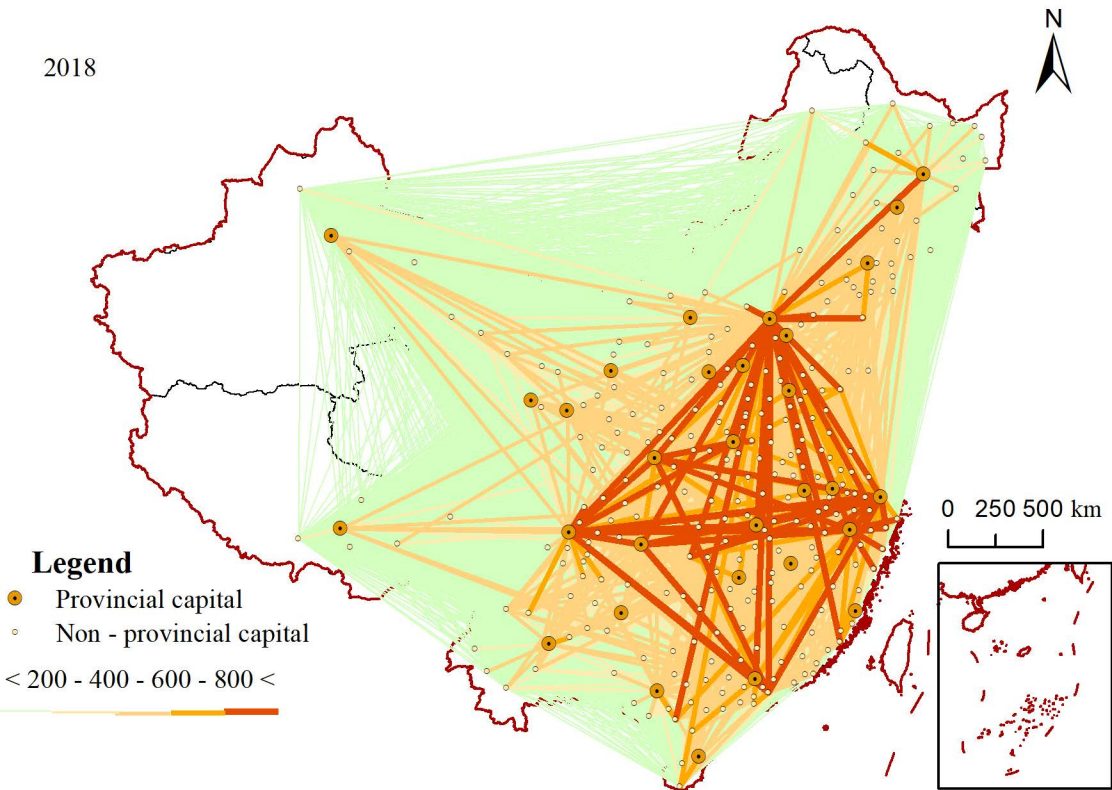
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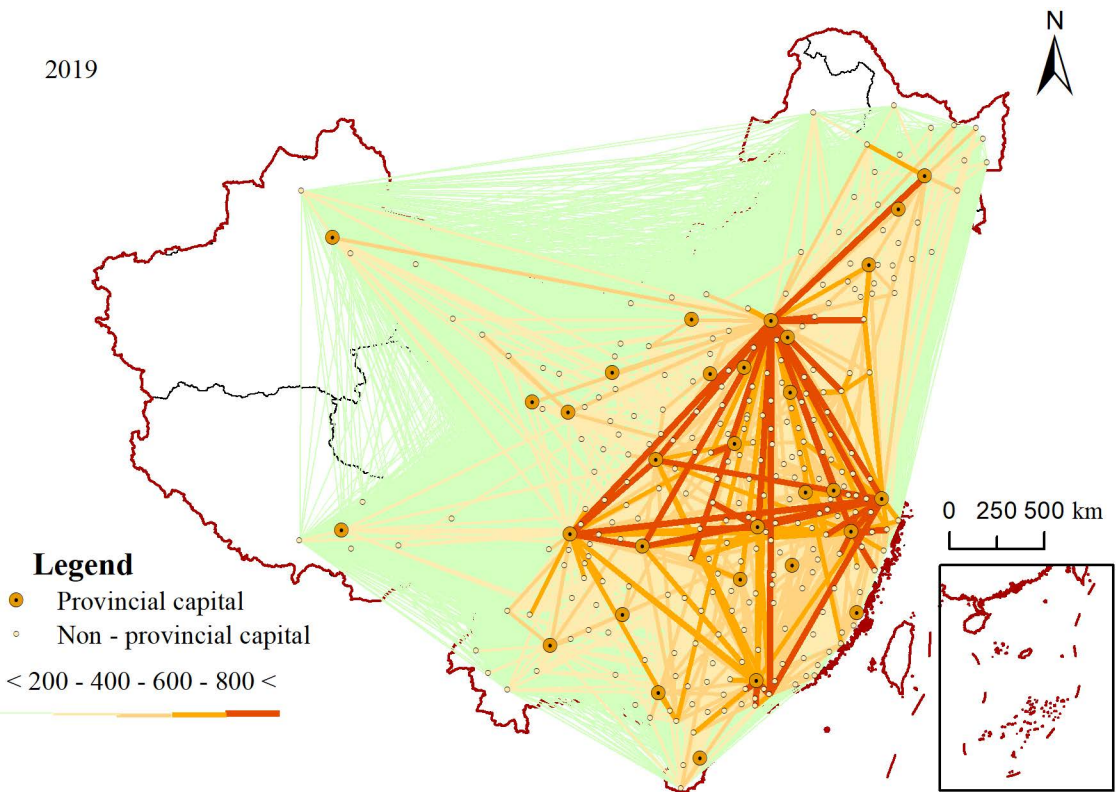
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