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Research on the City Network of Guangdong, Hongkong and Macao from the Perspective of Information Flow: Analysis based on Baidu Index

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Abstract. *In the context of the rapid development of informatization and globalization, the theoretical methods of urban scholars have shifted from a 'space of places' appraoch, which looks at geographical areas, to a 'space of flows' approach, which is based on flows of people, goods, capital, and information between cities. The rapid development of the Internet makes the connections between cities more dynamic than ever before. The subject of this study are cities in three provincial administrative units in Southern China: Guangdong, Hong Kong and Macao. The development of the Internet provides an opportunity to analyse the relationships between the cities in this region from the viewpoint of information flow. Using the area distribution model in Baidu Index (a website of the Baidu company), this study recorded the web search volume, simulated the information flows, and analysed the network correlation degrees between the cities in Guangdong, Hong Kong and Macau. The conclusions are: (1) from the perspective of information flow, the city network in Guangdong, Hong Kong and Macao has a clear 'core-periphery' structure, which amplifies the difference in urban hierarchy between big and small cities; (2) the cities in the traditional Pearl River Delta core region have a stronger ability to aggregate information flows and geographical proximity reflects information flow; (3) information flows between the cities in Guangdong and Hong Kong and Macao are not smooth, and thus needs to be improved.*

Keywords. *City network, area of Guangdong-Hongkong-Macau, information flow, Baidu Index.*

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Abstrak. *Dalam konteks perkembangan informatisasi dan globalisasi yang pesat, metode teoritis para peneliti perkotaan telah bergeser dari pendekatan 'ruang tempat' yang melihat wilayah geografis, ke pendekatan 'ruang arus' yang didasarkan pada arus manusia, barang, kapital, dan informasi antar kota. Pesatnya perkembangan internet membuat hubungan antar kota lebih dinamis dari sebelumnya. Subyek penelitian ini adalah kota-kota di tiga unit administrasi provinsi di Cina Selatan: Guangdong, Hong Kong, dan Macao. Perkembangan Internet memberi kesempatan untuk menganalisis hubungan antara kota-kota di wilayah ini dari sudut pandang arus informasi. Dengan menggunakan model distribusi area pada indeks Baidu (sebuah situs perusahaan Baidu), makalah ini mencatat jumlah pencarian web,*

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mensimulasikan arus informasi, dan menganalisis tingkat korelasi jaringan di antara kota-kota di Guangdong, Hong Kong dan Macau. Kesimpulannya adalah: (1) Dari perspektif arus informasi, jaringan kota di Guangdong, Hong Kong dan Macao memiliki struktur 'inti-pinggiran' yang jelas, yang memperkuat perbedaan dalam struktur hirarki perkotaan antara kota-kota besar dan kecil; (2) Kota-kota di wilayah inti Pearl River Delta tradisional memiliki kemampuan yang lebih kuat untuk mengumpulkan arus informasi dan kedekatan geografis juga mencerminkan arus informasi; (3) Arus informasi antara kota-kota Guangdong dan Hong Kong dan Macao tidak lancar, sehingga perlu ditingkatkan.

Kata Kunci. *Jaringan kota, wilayah Guangdong-Hongkong-Macau, arus informasi, Indeks Baidu.*

Introduction

The Guangdong-Hong Kong-Macau region is situated in the southern area of China's mainland. It includes Guangdong Province, which is the frontier of China's reform and opening-up, and Hong Kong and Macau, two special administrative regions (SARs). The cities in Guangdong Province, Hong Kong and Macao have experienced relatively long-term institutional barriers and economic differences, and had quite little social and economic exchange before the 1980s. Because of the opening up and fast development of the cities in Guangdong, the economic development gap between the cities in Guangdong and Hong Kong/Macao has been gradually narrowing and its relationship with Hong Kong and Macao is moving from fragmentation to integration. From the regional economy perspective, the development between the Greater Pearl River Delta (including Hong Kong, Macau and Guangdong's Pearl River Delta Region) and Guangdong's 'East Wing', 'West Wing' and 'Northern Mountain Region', three less developed areas, is very unbalanced.

In 2016, the New Urbanization Plan of Guangdong Province (2016-2020) stated that it is necessary to promote optimal development in the Pearl River Delta and revitalization and development of the eastern, northern and eastern areas of Guangdong, and strengthen the coordination and integrity of the region. In the new era, with a 'new normal' and the 'Belt and Road' initiative, challenges and opportunities coexist. The development of this region requires enhancing relations between the urban agglomerations of the Pearl River Delta and Hong Kong and Macao and jointly promoting the development of the region's core values and promoting coordinated development of peripheral cities in Guangdong to truly achieve regional coordination. In order to promote regional coordinated development it is important to understand key issues such as the spatial relationship between the cities in Guangdong, Hong Kong and Macao and the relationship between the core area and the surrounding areas in the Pearl River Delta. Hence, it is necessary to study the spatial organization relationships between Guangdong, Hong Kong and Macao.

Based on the information flows as represented in Baidu Index, this paper explores the city network between Guangdong, Hongkong and Macao in the information age, and analyses the development status of regional cities based on information flow and other statistics. Based on the information flow perspective, it re-interprets the 'core-edge' structure of Guangdong-Hong Kong-Macao and extends the methodology for describing city networks, demonstrating why urban planning in the Internet era must take into account the integration and application of information and the Internet.

Review of Relevant Research

With the more and more frequent exchanges of people, goods, capital and information between cities, the interconnections of city networks are becoming increasingly strong. Urban researchers increasingly stress the importance of city networks at the regional scale. Many researchers have argued that regional planning should pay attention to the 'space of flows' (Lai et al. 2015).

Since the end of the last century, the paradigm for studying urban and regional spatial organization has gradually changed from '*central place theory*' to '*city network theory*' (Ma et al. 2012). The space of flows (Castells 1996) is an innovative idea in city network research. Professor Manuel Castells, who proposed the concept, and others who have studied the space of flows believe that with the deepening of globalization and information technology, cities are no longer independent material entities. They are increasingly impacted by external elements. The relationship between cities can no longer be understood by analyzing just the 'space of places' of the entity (Castells 2010). The economic trade between multinational corporations and information transfers by people in different regions can be completed in a short time through the network. These 'flow elements' flow intricately between the nodes of the network and become decisive forces in the spatial form of the dominant regional organization (Taylor, Catalano et al. 2002). According to sources on 'relational data' between cities, the study of city networks can be divided into three categories.

The first category involves the measurement and research of dynamic 'flow factors' such as population flows (Wei et al. 2016, Yao et al. 2016) and traffic flows (Shin and Timberlake 2000, Burns, Cladera et al. 2008, Dong et al. 2013), which show intercity interaction characteristics directly (such as direct traffic surveys) and indirectly (such as mobile phone signaling and traffic flight simulation). These reflect the role of the flow of people and materials between the cities in an existing urban system.

The second category involves the measurement of economic ties between important urban enterprises. The 'network approach' model of the Global and World City Network (GaWC) is representative for this approach. In recent years, Chinese scholars have used similar research methods to explore city networks from the perspective of the number of enterprises and their branches (Zhao et al. 2010, Cheng et al. 2016), and the organization contact in advanced producer service industries (Tang et al. 2010, Zhao et al. 2012).

The third category involves the measurement and study of information flow including interactive relationships between people's telecommunications and Internet searches between cities. The approach adopted in this paper belongs to this category.

In the information age, the Internet is becoming more and more convenient for data communication and resource acquisition, and connections between cities no longer rely solely on entity infrastructure. The popularization of the Internet platform makes the ability to represent urban connections by appropriate information flows more and more prominent, and many scholars have explored this field (Zhen et al. 2012, Xiong et al. 2014, Cao et al. 2016). Even though information flow is among the elements of flow that can be measured in urban and regional studies, in general it still has not attracted enough attention from planners. However, searching, shopping, and communication through the Internet have become inseparable from human activities and thus information flows reflect relationships between people in one city and other cities. The study of Guangdong, Hong Kong and Macao in this paper, on the one hand,

complements the study of the city network by information flow in this area; on the other hand, it breaks institutional barriers of analysis of the relationship between mainland cities in China and China's two special administrative regions-Hong Kong and Macao, which would have been very difficult if only traditional methods had been used.

Research Method

Data Selection

With the development and spread of information technology in China, the use of the Internet for communication, data transmission and news consultation has become an indispensable part of people's lives. According to the fortieth Statistical Report on China's Internet Development, released in July 2017, the number of Internet users in China had reached 751 million and the Internet penetration rate was 54.3%. The number of search engine users had reached 609 million and the utilization rate was 81.1%.

More and more scholars realize that the Internet is not only convenient for our lives, but also generates a huge amount of network flow data that can be used as an important source for research on city connectivity as well as economic and industrial analysis. The number of researches based on web search volume, traffic data and location information is growing and scholars from urban planning are increasingly cooperating with large internet companies like Sina (Zhen et al. 2012), Tencent, and Baidu (Ye et al. 2017).

Baidu Index is a professional data sharing platform based on Baidu's statistical data about mass behavior of netizens. Its reflects the number of searches for a noun in a Baidu search engine over a period of time (Figure 1). According to data from StatCounter, an Internet flow monitoring site, the use of Baidu's search engines in China accounted for 77.32% of all search traffic in 2017. In general, the greater the economic and industrial ties between cities, the greater the attention of their residents for each other. Baidu Index is based on the search volume from one city's residents related to other cities. It reflects the attention of the residents from one city for other areas reasonably accurately and is a reasonable proxy for the information flow between cities.

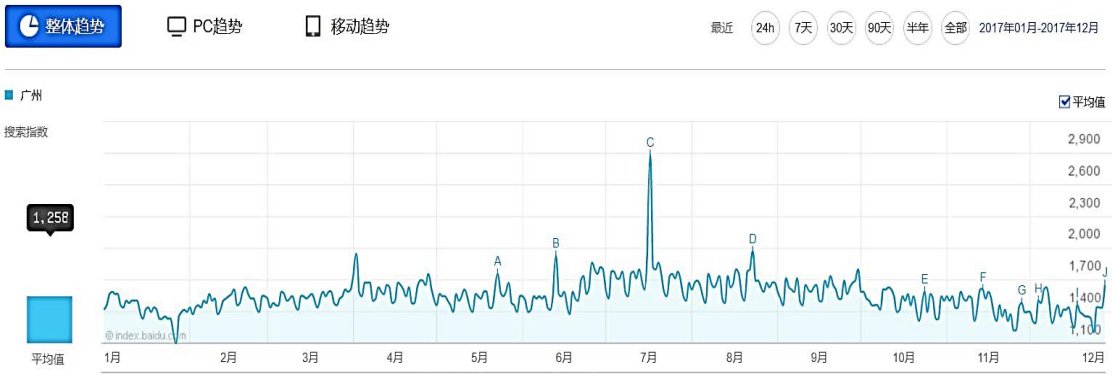

Figure 1. Example of the Baidu Index search interface.
Source: Baidu Index official website (http://index.baidu.com).

Research Methods and Purposes

Based on previous scholars' methods, the strength and weakness of connectivity between pairs of cities based on information flow can be expressed as the product of the Baidu Index between two cities. The original data is the attention of residents from city *A* for city *B-Ab* (and the attention of residents from city *B* for city *A-Ba*). The relationship between *A* and *B* based on information flow is *Rab*; the total amount of information flow in urban area *A* is *Xa* in these 23 cities:

$$Rab = Ab \cdot Ba \tag{1}$$

$$Xa = Rab + Rac + \cdots + Raw(23\ \text{cities}) \tag{2}$$

We collected Baidu Index data from the Baidu Index website between every pair of cities among 23 cities in Guangdong, Hong Kong and Macau, from July to September, 2017.

Through data calculation, the network relation degree and the total amount of urban information flow between the 23 cities in the Guangdong, Hong Kong and Macao region from the perspective of information flow can be derived. Based on this, we will further analyze and try to understand:

(1) The structure characteristics and the hierarchical relationship of the city network of Guangdong, Hong Kong and Macao from the perspective of information flow.
(2) The influence and relationship between the 'dual core' of Guangzhou and Shenzhen in the province of Guangdong.
(3) The relationship between Guangdong, Hong Kong, and Macao based on information flow.

Analysis and Main Findings

The 'Center-Periphery' Differentiation of the Whole Structure

The city network information flows of Guangdong, Hong Kong and Macao can be represented spatially using ArcGIS. The 'core-periphery' structure is very obvious when represented this way (Figure 2). Guangzhou-Shenzhen is the axis of Guangdong, Hong Kong and Macao. The regional core area is formed by 11 cities around the Pearl River Delta. The three pairs of cities with the highest degree of connection are Guangzhou-Shenzhen (1,723,080 connections), Shenzhen-Dongguan (1,031,016 connections) and Guangzhou-Foshan (1,010,100 connections). These four cities –Guangzhou, Shenzhen, Foshan and Dongguan – are the four cities with the highest level of economic development in Guangdong. In addition to the strong links between Guangzhou and Shenzhen, the integration of Shenzhen and Dongguan and the unifying development of Guangzhou and Foshan have been dramatic in recent years. In contrast, information flow in the peripheral cities is relatively weak; the total amount is generally much smaller than in the cities in the Pearl River Delta. For example, Zhanjiang, with the highest volume of information flow among the peripheral cities, is only ninth in the total ranking. The information flow between the two special administrative regions – Hong Kong and Macao and Guangdong's municipalities – is not closely related due to institutional restrictions, which will be discussed later.

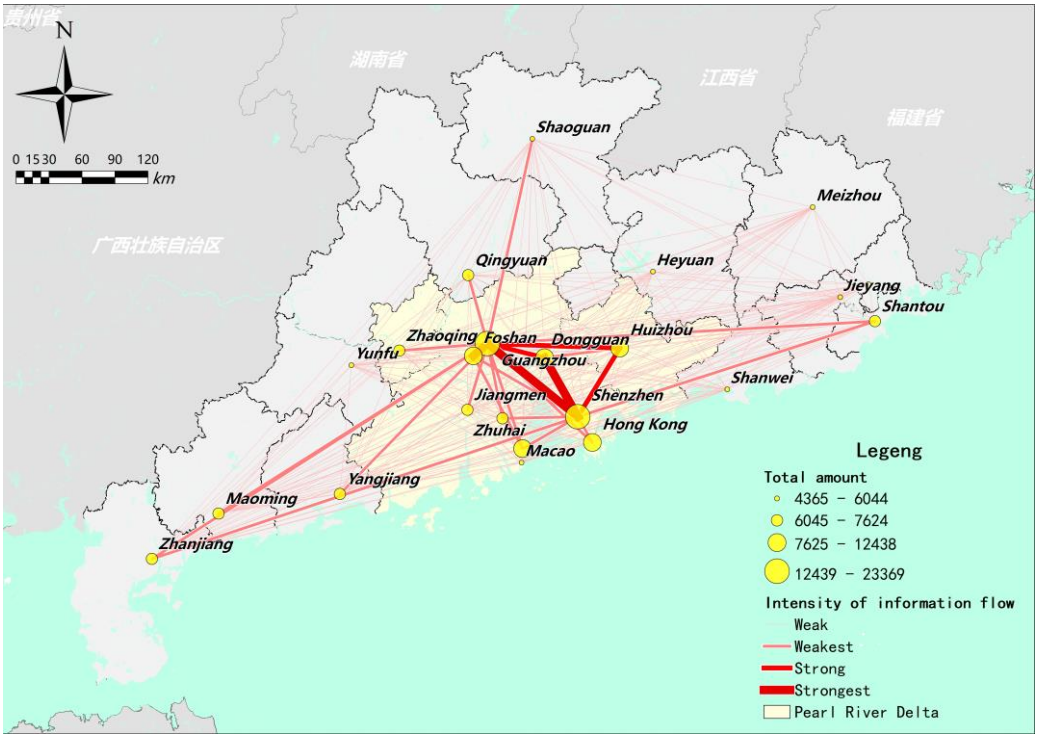

Figure 2. The city network based on information flow in Guangdong-Hongkong-Macau (2016). Source: Drawn by the authors on ArcGIS and based on network analysis.

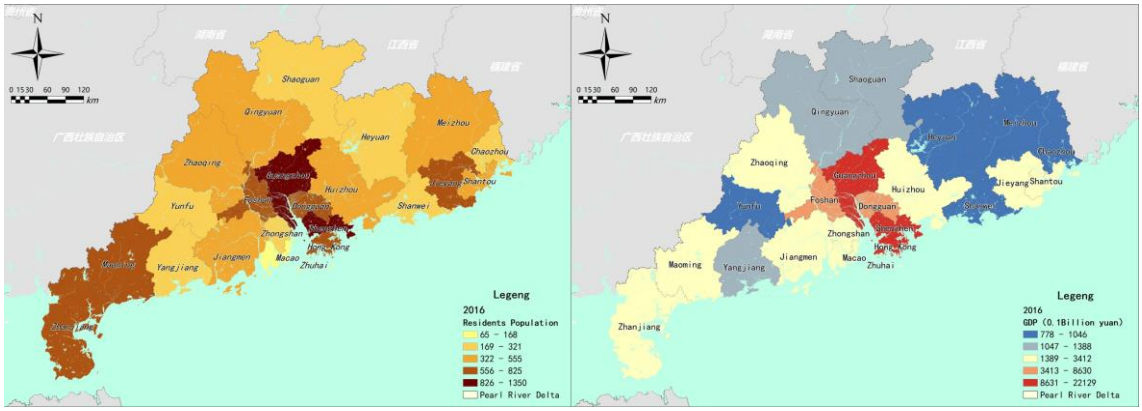

Figure 3. Urban resident population (left) and GDP (right) in Guangdong-Hongkong-Macau (2016). Source: Drawn by the authors on ArcGIS and based on Guangdong statistical yearbook (2016).

Two main indicators commonly used in urban planning to reflect a city's socio-economic volume and overall level of development are resident population and gross domestic product (GDP) (Figure 3). However, because these data are directly linked to the geographical areas of a city, indicators such as population density and GDP per capita, which reflect the degree of population concentration and economic performance, are frequently used. Based on an analysis of these indicators, the core and circle structure of the Pearl River Delta is obvious (Figure 4).

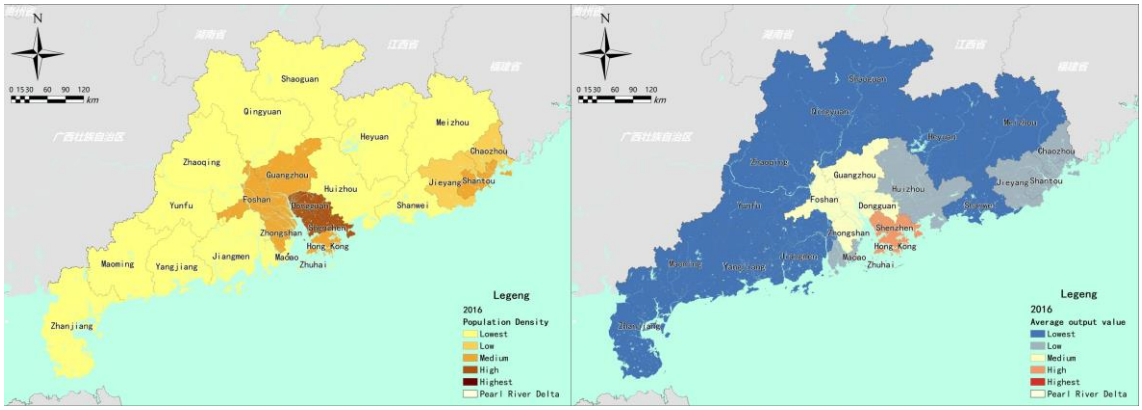

Figure 4. Population density (left) and unit value (right) distribution. Source: Drawn by the authors on ArcGIS and based on Guangdong statistical yearbook (2016).

Using Statistical Package for the Social Sciences (SPSS) we conducted a comparative analysis of the total amount of information flow and the resident population and information flow in the cities in Guangdong Province:

(1) Exploring the relationship between the total amount of information flow and the resident population in each city (Figure 5), it was found that the cities in Guangdong can be divided into three levels: Guangzhou and Shenzhen are at the first level, Foshan and Dongguan are at the second level, and the rest of the cities belong to the third level. Regression analysis using the resident population as an independent variable found the standard residuals of the three cities of Zhuhai, Guangzhou and Shenzhen to be greater than 1, indicating that their status based on information flow in the region is significantly higher than their population would suggest. This also indicates that the information impact of these three cities is stronger than the theoretical value relative to their population sizes.

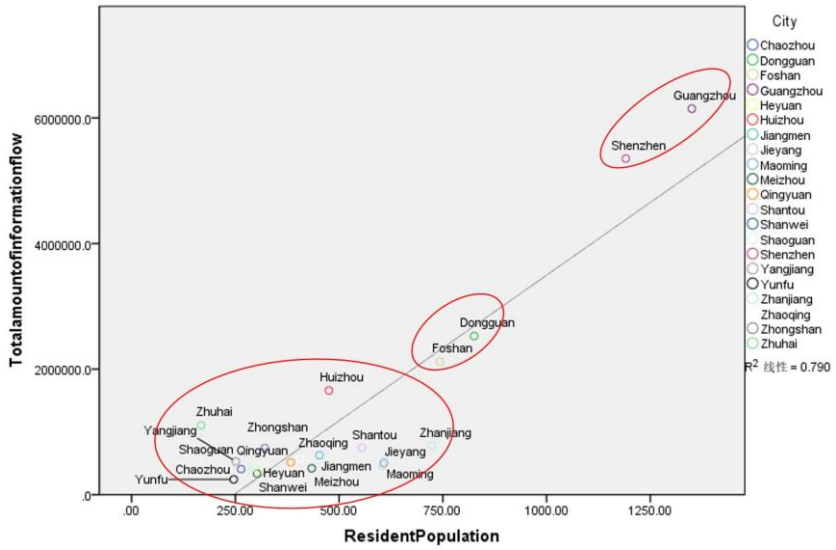

Figure 5. Regression analysis of the total amount of information flow and the resident population. Source: Drawn by the authors on SPSS based on Guangdong statistic yearbook and network analysis.

(2) The relationship between information flow and the level of economic development as measured by GDP level is closer than the relationship between information flow and total population (Figure 6), (R2 reaches 0.97), while the structure of the hierarchy is basically the same. However, this regression image shows that the cities in these three clusters are more compact and the gap between the three city levels is also greater than the one above (Figure 5).

The hierarchical differences between big and small cities in the Pearl River Delta are greater both in terms of social economy and urban network based on information flow. At present, the Chinese government is pursuing coordinated development and urban planning needs to pay more attention to imbalances in regional development. Except for Hong Kong and Macao, due to their special status, the cities in the region can be divided into three categories: 'regional core cities', 'secondary core cities' and 'other cities'. Some cities, such as Huizhou, Zhuhai and Zhongshan in the 'other cities' category, have better economic development and greater locational advantages than the slower developing peripheral cities.

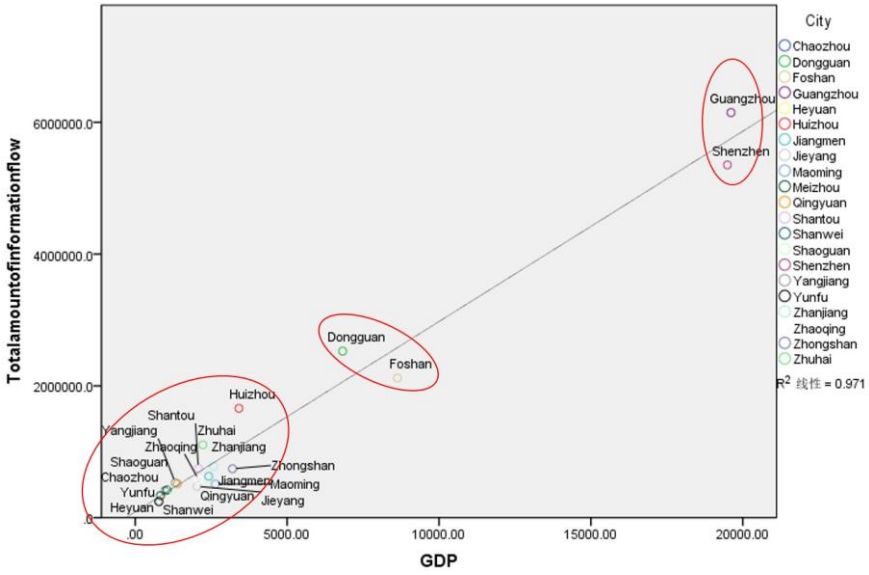

Figure 6. Regression analysis of the total amount of information flow and GDP level. Source: Drawn by the authors on SPSS based on Guangdong statistic yearbook and network analysis.

Guangdong's 'dual core' and information flow

The relative connectivity degree method proposed by Peter Taylor (2001) has been applied to the analysis of regional network structures and to identify the hinterland of big cities. This application avoids the problem of neglecting weak links when judging the absolute value of direct network connections (Li et al. 2016). The specific method used here is as follows. For a city *i*, the network correlation of *i* and another city *j* in the region *Cij* can be determined by a regression analysis, which shows the total correlation of city *j*-*Dj*, and the residual *Rij*:

$$Cij = a + bDj(+Rij)(j = 1,2,\cdots,n, j \neq i) \quad (3)$$

If *Rij* is positive, the relative connectivity between cities *i* and *j* is stronger than usual and the cities can be characterized as over-linked. On the other hand, if the relative connectivity between cities *j* and *i* is weaker than usual, the relative connectivity is under-linked. Using

bounds of -1, 0, 0.5 and 1, the standard residuals based on the above calculation can be divided into 5 classes. The relationship between other cities and *i* can be divided into 'weakest links', 'weak links', 'medium ties', 'strong ties' and 'strongest ties'. A city with 'strongest ties' (*Rij* > 1) can be defined as part of the hinterland of the target city, *i* (Taylor 2001).

Hong Kong and Macao, as special administrative regions, have relatively little impact on the development of peripheral cities in Guangdong Province. At present Guangzhou and Shenzhen as megacities in Guangdong Province operate as a 'dual core', driving the comprehensive and coordinated development of the Pearl River Delta as well as the whole Guangdong Province. The resident population in Guangzhou and Shenzhen accounts for about 22% of the total in the area of Guangdong, Hong Kong and Macau, but their GDP accounts for about 36% of the total for the region. In recent years, the GDP gap between Guangzhou, Shenzhen with Hong Kong is getting smaller. Guangzhou and Shenzhen have the potential to become 'global cities' like Hong Kong. Statistics on the total amount of information flow in each city showed that the dual core Guangzhou-Shenzhen accounted for 41% of the total information flow in the region, larger than the proportion of GDP (Figure 7). This reflects the fact that major cities like Guangzhou and Shenzhen have a powerful ability to lead the city region because of their dynamic function in the region.

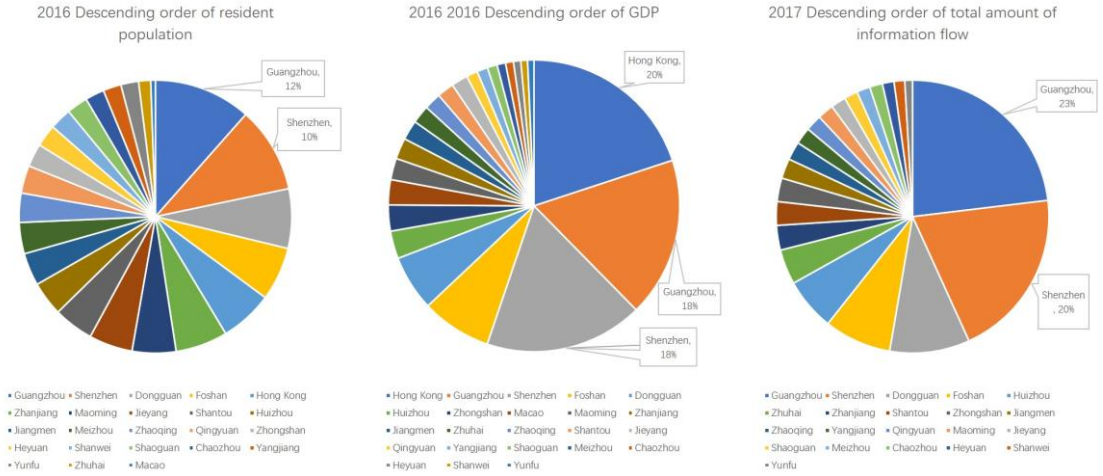

Figure 7. Percentages of population, GDP and information flow in the region by city.
Source: Drawn by the authors based on and based on Guangdong statistic yearbook and network analysis.

Identifying the absolute value by measuring connectivity between Guangzhou, Shenzhen and other cities is important. The above analysis is based on absolute values. Using a relative degree method, we can objectively estimate the relationship between other cities and Guangzhou and Shenzhen, and we can see if the relationship between small and medium-sized cities and big cities is in a higher or lower position in the region. Our analysis showed that Foshan (R = 2.26) and Yunfu (R = 1.07) are in fact part of the hinterland of Guangzhou, while Dongguan (R = 2.65) and Huizhou (R = 1.03) are part of the hinterland of Shenzhen. Cities having weak links with Guangzhou (R < -1) are Huizhou and Hong Kong, and cities having weak links with Shenzhen (R < -1) are Hong Kong, Zhuhai and Foshan. Considering the locations of these cities, we found that geographic proximity has a great influence on the degree of relative connectivity. The network hinterland is generally close to the core cities in the region. This is

conducive to undertaking the transfer of industries and populations in large cities, which would result in an even higher information flow in these cities.

Combining the absolute values of connectivity and the relative connectivity degrees in the city network (Figure 8), we can see that cities that have stronger regression values with Guangzhou are mainly in the West and North. Shenzhen's residuals are also higher. The areas that have better information flow with Shenzhen based on the regressive values are in the eastern part of the region. Although the absolute value for Foshan, Guangzhou with Shenzhen is higher than for other cities, they don't reach the ideal values than they should achieve.

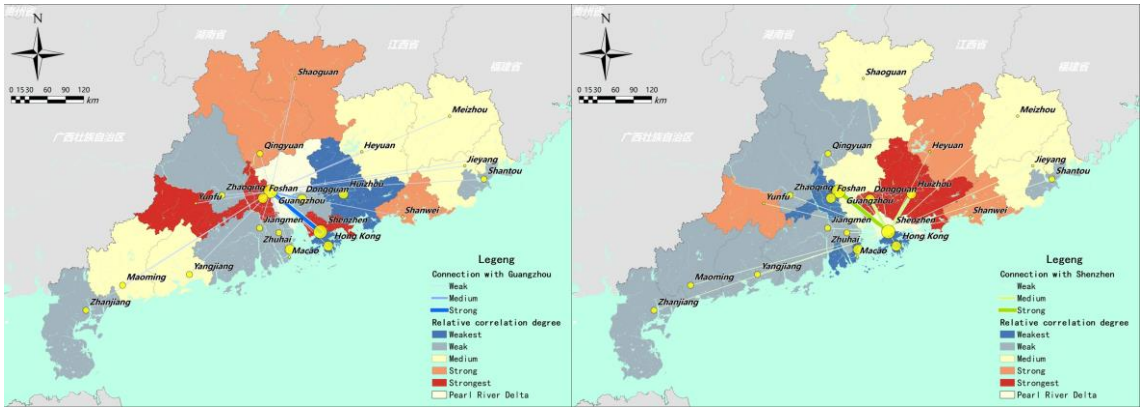

Figure 8. Correlation value with other cities and network hinterland discrimination: Guangzhou (left) and Shenzhen (right). Source: Drawn by the authors and based on network analysis.

The Relationship between Guangdong and Hong Kong/Macao based on Information Flow

Hong Kong and Macao were occupied by western countries in 19th century until they were returned to China in later 1990s and designated as special administrative regions (SARs). Long-term institutional differences and current Internet restrictions have led to a poor transmission of information flow between Hong Kong, Macao and mainland cities. Residents in mainland China mostly use Baidu as their search engine, while people in Hong Kong and Macao mainly use Google. This results in the levels of search linkage with Hong Kong and Macao being much lower than the real city connectivity when the city network of Guangdong, Hong Kong and Macau is constructed based on Baidu Index. It is evident that the inaccurate Internet measure does not reflect reality.

Here, we use the 'search index' to Hong Kong and Macao from the cities in Guangdong to measure the degree of public concern for Hong Kong and Macao.

(1) From the total amount of public concern (Figure 9), the total amount of public concern of Guangdong cities for Hongkong is 8,639, while the total amount of public concern to Macao is 5,428. The degrees of concern between these two cities are far smaller than those of the cities in Guangdong and don't match their own economic strength because of the current Internet restrictions. Thus, it shows that China's Internet market is not open enough. Good connections between Hong Kong, Macao and the cities in Guangdong should not only be a propaganda slogan.

(2) From the perspective of population size and total amount of public concern from the cities for Hongkong and Macao based on Internet searches (Figure 10). Some cities' public concern for Hongkong based on information flow is relatively high (compared to its own resident population), such as Shenzhen, Zhuhai, Zhongshan (R are all greater than 0.8), while some cities' public concern for Macao based on information flow is relatively high (relative to permanent resident population) is Zhuhai, Guangzhou, Zhongshan and Shenzhen (R is greater than 1). The cities that have higher concern for Hong Kong and Macao are distributed in the Pearl River Delta.

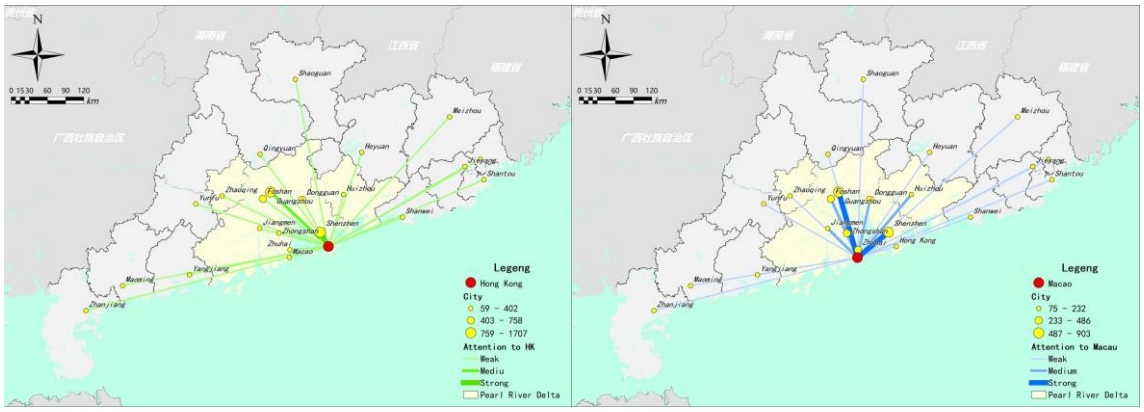

Figure 9. Degree of public concern to Hongkong (left) and Macao (right). Source: Drawn by the authors and based on network analysis.

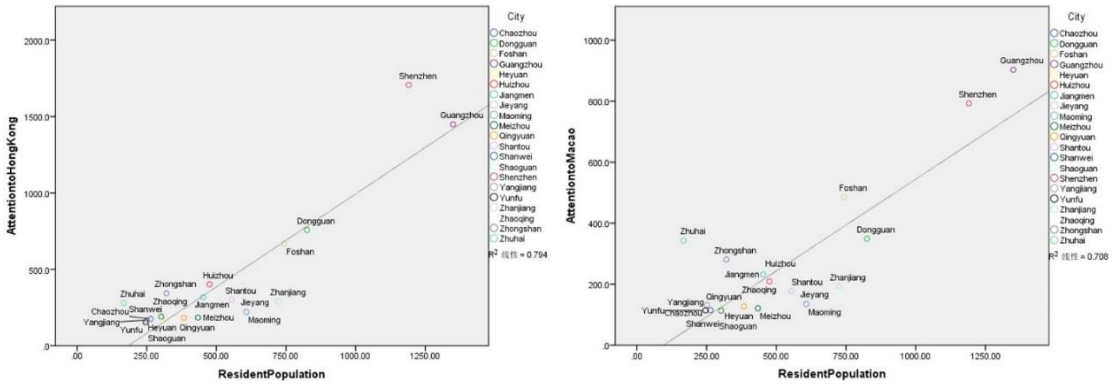

Figure 10. Comparison between degree of public concern for Hongkong (left) and Macao (right) and the populations of these cities. Source: Drawn by the authors on SPSS and based on network analysis.

Based on our analysis, barriers in information flow between Hong Kong, Macao and Guangdong are still significant. If China wants to promote the integration of the 9 cities in the Greater Pearl River Delta and the Guangdong-Hong Kong-Macao Greater Bay Area, these Internet barriers as well as others must be eliminated. In the information age, a smooth and unimpeded Internet information network can promote long-distance communication between people, enterprises and institutions and lay a solid foundation for the efficient interconnection of entity space. Overcoming existing information flow barriers can help to make the Guangdong-Hong Kong-Macao Greater Bay Area a world class megacity region and in turn help drive the whole Guangdong province to achieve 'development of high quality'.

Conclusions

Based on Baidu Index, the volume of people's internet searches, the information flows between Guangdong, Hongkong and Macao were calculated and a city network based on information flow in Guangdong, Hong Kong and Macao was built. Through the analysis of the structural characteristics of the urban network in this region, combined with statistical indicators, the following conclusions can be drawn. First, there is a clear 'core-periphery' structure in the city network in the Guangdong, Hong Kong and Macao region. The information flow gap between cities within the Pearl River Delta and external cities is huge. City systems can be formed at four levels: (1) the core cities of the region, (2) the secondary center cities related to the core cities, (3) medium-sized cities with good locations, and (4) peripheral cities. This research found that with respect to information flow, the regional coordinated development policy initiated by the China central government needs to be better implemented. Second, the dual core of Guangzhou and Shenzhen has a strong ability to concentrate information flow within the region. Megacities' ability to concentrate information flow is greater than that of the economy and population alone would imply. Cities with better connections than statistically expected values are mainly distributed around the core cities. Third, currently, Hong Kong and Macao are not well connected with the Guangdong cities through the Internet due to the current restricted status of search engines. The existing connections are mainly concentrated near the Pearl River Delta. Fourth, both in policy and technical terms, good connections between Hong Kong, Macao and the cities of Guangdong Province should be achieved as soon as possible. Information connections would play a crucial role in the construction of the Guangdong-Hong Kong-Macao Greater Bay Area in particular.

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