Empirical Analysis of City Contact in Zhujiang (Pearl) River Delta, China

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Abstract: In traditional urban geography, city contact research is a classic study element in city research. In general, researchers use the traditional gravity model to characterize the contacts that exist between two cities. The traditional gravity model assumes ideal conditions, but these preconditions and their results often do not exist in realistic conditions. Thus, we used a modified gravity model to characterize the city contacts within a specific region. This model considers factors such as intercity complementarities, government intervention, and the diversity of the transportation infrastructure which is characterized as the transportation distance instead of the traditional Euclidean distance. We applied this model to an empirical study of city contact in the Zhujiang (Pearl) River Delta (PRD) of China. The regression results indicated that the modified gravity model could measure city contact more accurately and comprehensively than the traditional gravity model, i.e., it yielded a higher adjusted R^2 value (0.379) than the traditional gravity model result (0.259). Our study also suggests that, in addition to urban-regional and metropolitan development, the complementarities of the basic functions of cities at the administrative and market levels, as well as the corporeal and immaterial levels, play very significant roles in the characterization of city contact. Given the complexity of city contact, it will be necessary to consider more relevant influential factors in the modified gravity model to characterize the features of city contact in the future.

Keywords: city contact; function complementarities; government intervention; gravity model; Zhujiang (Pearl) River Delta (PRD); China

1 Introduction

City contact refers to complex connections such as natural ties, economic linkage, population movement contacts, social interaction contacts, transmission service contacts, information contacts, political and administrative contacts, and organization contacts, which occur via a developed traffic transportation system and information networks (Hesse, 2010). According to the flow space theory, cities gain and accumulate wealth and power because of capital flow and information technology flow rather than where they are located (Castells, 2000). All economic and social activities are based on contacts within cities, while regional relationships are mediated via crowd flow, commodity flow, capital flow, and information flow, *etc.* (Smith and Timberlake, 1995; Liu and Taylor, 2011).

This view suggests that city contact research can not rely solely on the data attributes of the city itself, because it must also be concerned with the relational data within cities (Taylor, 2004). Camagni and Salone (1993) divided a city into the infrastructure, population, and economic activity interactions. To reflect city contacts more realistically and accurately, the former can be re-

ferred to as the roadway network and waterway network while the latter considers various factor flows, such as population flow and economic activities. Flow linkage is an abstract concept compared with the roadway network, so some scholars have conceptualized the factor flow based on a division of function and form, where functions refer to economic, political, social, and cultural functions, whereas form refers to the population, materials and information (Smith and Timberlake, 1995). This approach provides more selective breakthrough points during further empirical studies of city contact.

There are two methods for measuring city contact. The first is a statistical analysis of the intensity, frequency, and direction of city contact, as well as the realistic regional transmission described by commodities, transportation, population, and information technology (Sassen, 1994; Friedman, 1995; Taylor *et al.*, 2002; Derudder *et al.*, 2007; Dai and Jin, 2008). The other method is based on a formula used to calculate spatial interactions, by quantitatively measuring the intensity and direction of city contacts (Dobkins and Ioannides, 2001; Roy and Thill, 2004; Luo *et al.*, 2008; Wu *et al.*, 2009). Current applications of the city contact model are the traditional gravity model (Lukermann and Porter, 1960; McArthur *et al.*, 2011; Zbeleznyak and Oleshchenko, 2011) or a city flow model (Liu and Cai, 2009). The traditional gravity model simply considers static data such as the population, gross domestic product (GDP), and quantitative employment data, so it can not fully reflect the actual city contact situation. Some researchers have tried to amend the model to some extent,

but the model still fails to characterize city contacts accurately (Meng and Zhao, 2011; Zhao *et al.*, 2011).

To measure city contacts more accurately using the gravity model, we combined the two methods mentioned above by using one-day origin-destination (OD) data and we modified the gravity model for city contact research by using several factors to study the Zhujiang (Pearl) River Delta (PRD). We introduced the comprehensive transportation distance, city function complementarities, and government intervention elements into the model, and we constructed a new modified gravity model. Our empirical study of city contact in PRD verified the effectiveness of the modified model and we concluded that combining the comprehensive transportation distance, function complementarities, and government intervention helped to elucidate city contacts in PRD.

2   Materials and Methods

2.1   Study area

PRD is located in the south of China, where it borders Hong Kong and Macao of China (Fig. 1). PRD comprises nine main cities (Guangzhou, Shenzhen, Zhuhai, Foshan, Dongguan, Jiangmen, Zhongshan, Zhaoqing, and Huizhou) and it was the earliest economic area to open up during China′s reform (National Development and Reform Commission, 2008). As a major economic area, PRD has experienced the fastest growth in urbanization and industrialization in China. In the planned economy era (before 1978), PRD was a mono-centric region, where Guangzhou (capital of Guangdong Prov-
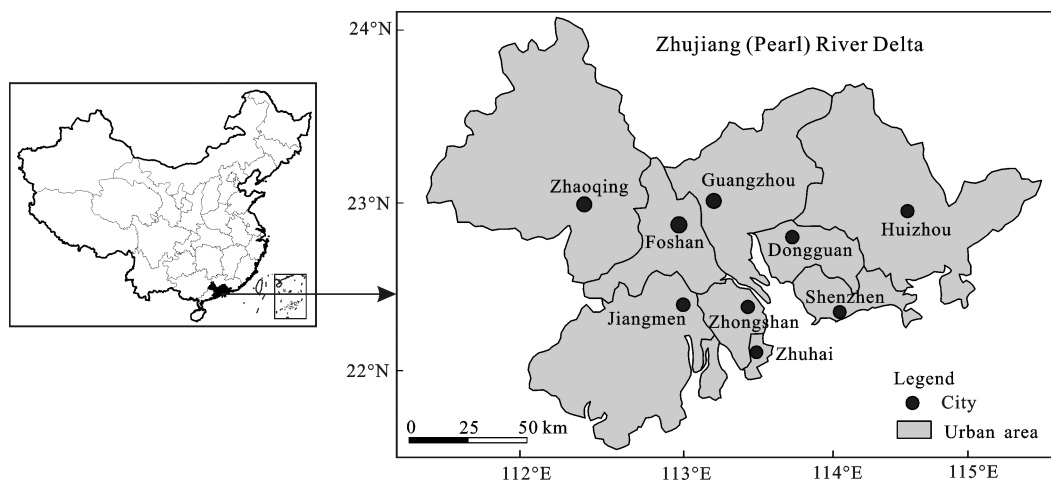

Fig. 1   Location of study area

ince) was the center. Guangzhou′s surrounding areas operated according to a separate development system with a typical urban-rural/industry-agriculture binary system, which had an obvious center-edge structure and there were few city contacts in PRD. From the early stage of the opening up period (from 1978 until the middle 1990s), PRD was a center for Hong Kong and Macao of China. In PRD, Hong Kong had enormous influences on the development of industries and cities, so people in the PRD exploited the advantages of their cultural, linguistic, and geographical relationships to attract investments from Hong Kong of China. However, the contacts between cities were not close during this development because there was a lack of coordination. Since the deepening of opening up (after the middle 1990s), city contact has strengthened in PRD and an obvious multi-polar economic development pattern has emerged in PRD.

2.2 Data sources

The data sources were as follows. 1) Twenty-four hour PRD passenger flow OD data from *the Pearl River Delta Region of Integrated Rail Transit Planning* (*modified version*) (Guangdong Development and Reform Commission, 2009), where the transportation types include public buses, private cars, water transport, railway travel, air travel, and all other means of transportation within cities. 2) Data on the population of nine cities, GDP, and the employees of 19 related industries during 2008 in PRD were obtained from *Guangdong Statistical Yearbook 2009* (Statistics Bureau of Guangdong Province, 2009) and *China City Statistical Yearbook 2009* (National Bureau of Statistics of China, 2010) (the 19 industries were farming, forestry, animal husbandry and fishery; mining and quarrying; manufacture; production and supply of electric power, gas and water; construction; transport, storage and postal services; information transmission, computer services and software; wholesale and retail trade; hotels and catering services; finance; real estate; leasing and business services; scientific research, technical services and geological prospecting; water conservation, environment, and public facilities management; residential services and other services; education; health care, social security and social welfare; culture, sports and recreation; public administration and social organization). 3) Other data, such as traffic data and intergovernmental cooperation agreement materials, were acquired from the nine cities′ appropriate official websites.

2.3 Methodology

City contacts refer to the interactions between cities, which are related to the integration of regional development and are an important constituent of regional harmony. Moreover, the production and strengthening of city contacts are affected not only by individual social and economic conditions, but also by factors that influence regional development, such as industrial suburbanization, government regulation policies, technological progress, and transportation (Zhou, 1998; Yao *et al.*, 2006; Zhou and Guo, 2007). The most widely used model of empirical study of city contacts is the traditional gravity model (Anderson, 2011) (see in Equation (1)). The traditional gravity model assumes that city contacts are related directly by a city′s scale, social and economic development level, and location. In general, a city with a higher population size has a greater level of economic development. Two cities that are located in closer proximity also have stronger ties (Zhou, 2003).

$$R_{ij} = \frac{\sqrt{P_i \times G_i} \times \sqrt{P_j \times G_j}}{d_{ij}^2} \qquad (1)$$

where R_{ij} is the relationship between cities i and j; P_i and P_j are the residential populations in city i and city j, respectively; G_i and G_j are the GDP of city i and city j, respectively; and d_{ij} is the distance between cities i and j.

The gravity model can reflect the basic regional structure of city contact, but the model considers a limited number of factors and places too much emphasis on the city′s own attributes while ignoring the internal and external forces that affect city contacts. Furthermore, the measurement of the distance between two cities should be related to reality instead of the simple Euclidean distance. Thus, the gravity model can not characterize the actual intensities of city contacts accurately, so it is necessary to introduce more influential factors into the model.

We argue that the real spatial relationship (not the simple Euclidean distance) and the relationships between cities can characterize city contacts better, but these factors are not considered by the traditional gravity model. The real spatial relationship can be explored by modifying the distance between cities and using the comprehensive transportation distance as a substitute. The relationships between cities can be divided into two

types: market relationships and government relationships. Market relationships can be expressed directly as city function complementarities while government relationships can be expressed as government intervention factors. Like the population and GDP factors, we make the geometric average of the production of market and government factors into the modified gravity model. After introducing these three variables simultaneously into the gravity model, the modified model is as follows:

$$R_{ij} = \frac{\sqrt{P_i \times G_i} \times \sqrt{P_j \times G_j}}{D_{ij}^2} \times \sqrt{f_{ij} \times g_{ij}}$$

$$f_{ij} = w_1 \times FCI_{ij} \quad g_{ij} = w_2 \times GII_{ij} \qquad (2)$$

where D_{ij} is the distance between cities i and j; f_{ij} is the market relationship between cities i and j; and g_{ij} is the government relationship between cities i and j. FCI_{ij} is the function complementarities index and w_1 represents other factors included in the market relationship, which is assumed a constant value. GII_{ij} represents the government intervention index and w_2 represents other factors included in the market relationship which is assumed a constant value.

Inter-city highway traffic is the main mode of transportation in PRD. First, each municipal government was regarded as the city center and a common route was selected between the city centers based on Google Maps (using Google Maps′ Self Driving Travel Recommendation route as the common line). Next, we measured each line section at different road levels (motorway, national highway, provincial road, freeway, and others), where we assumed a motorway speed of 100 km/h, national highway speed of 80 km/h, provincial road speed of 60 km/h, freeway speed of 80 km/h, and other speeds of 40 km/h) and we used Equation (3) to obtain the intercity road traffic distance based on the average value for all routes.

$$R_{road} = \sum_{i=1}^{n} w_i \times R_i \qquad (3)$$

where R_{road} is the road traffic distance; w_i is the coefficient of road level i; R_i is the length of the corresponding road level i; and n represents the quantities of different road levels. The speed was faster at higher road levels, so the time required was reduced and contacts were easier (Guo and Wang, 2009; Yan *et al.*, 2009). The reciprocal of the speed of each road type was used

as a coefficient to calculate the relative contact level. Lower results indicated shorter road traffic distances and closer city contacts.

The development of inter-city rail transit (at present, the PRD railway between the main cities comprises four categories: bullet train (D), direct (Z), express (T), and fast (K). According to the actual speeds of the trains we defined four types of speed, i.e., 160 km/h, 120 km/h, 100 km/h, and 80 km/h, respectively, means that the potential routes of city contact have increased. Using Equation (4), we calculated the railway traffic distance.

$$R_{rail} = \frac{\sum_{i=1}^{n} w_i \times R_i}{n} \qquad (4)$$

where R_{rail} is the railway traffic distance; w_i has the same meaning as in Equation (3); R_i *is* the distance of the corresponding train type i. The passenger data were obtained from China Railway Customer Service Center. Only direct routes were selected and we did not consider transfers. If two cities lacked a direct train, the default value of the city contact by railway was 0.

With respect to the modes of travel used by passengers in PRD, road travel accounted for most of the passengers with 85.3% of the total travel, which comprised 68.6% on highway buses and self-drive at 16.7%, while rail travel for 6.3%, civil aviation travel for 1.4% and water transportation for 0.9% (Data are from China Railway Siyuan Survey and Design Group Co., Ltd.). In this study, we assumed a road weight of 0.9 and a railway weight of 0.1, where we ignored all other modes of transport. Thus, we obtained Equation (5).

$$D_{ij} = 0.9 \times R_{road} + 0.1 \times R_{rail} \qquad (5)$$

City contacts emerge from the demands of city function complementarities and city contacts are stronger with better city function complementarities. The city function complementarities are related to the Location Quotient (LQ) and there is usually a larger difference in the LQ between cities with stronger city complementarities. To calculate the LQ for nine cities based on 19 industries in PRD, we examined all of the different functional divisions among cities, in strict accordance with the industry classification in *China City Statistical Yearbook 2009* (National Bureau of Statistics of China, 2010).

In general, if there were more employees in a de-

partment in a city, more products or services were provided by the department and the department's economic function was higher. Thus, we used the LQ of the employment by departments to represent a city's dominant function, as follows (Zhou, 2003):

$$LQ_{ik} = \frac{E_{ik}/E_i}{E_k/E} \tag{6}$$

where LQ_{ik} represents the LQ of department k in city i in PRD; E_{ik} represents the employees in department k in city i; E_i represents the total employment in city i; E_k represents the total employment in department k in PRD; and E represents the total employment in the 19 industries in PRD. We used Equation (7) (Krugman, 2002) to calculate the function complementarities index between cities i and j, as follows:

$$FCI_{ij} = \sqrt[19]{\prod_{k=1}^{19}\left|LQ_{ik} - LQ_{jk}\right|} \tag{7}$$

Government intervention elements usually have positive or negative effects on city contacts. However, cities can sometimes act in their own interests by engaging in protectionist behavior. This type of intervention has a restrictive effect on city contact. Local governments have a responsibility to promote cooperation between cities to overcome their own inadequate resource development conditions and to formulate cooperation agreements, and these interventions have major effects on promoting and protecting city contacts. The requirements for the *Construction of Urban Integration in the Pearl River Delta Region Reformation and Development Planning Outline* (*2008–2020*) to promote inter-governmental cooperation are becoming stronger, and these cities have issued a series of relationship agreements. Government intervention is a social administration element that can not be evaluated quantitatively. Moreover, it takes a long time for an agreement to take effect, regardless of the agreements among different stakeholders, so it is difficult to quantify in a standard manner. Thus, we propose an approximate characterized method based on the Year 2009[①]agreement signed among these cities.

Obviously, the city contacts will be stronger if more cooperative agreements are signed, but the marginal utility of strengthening city contacts diminishes. Thus,

we used the function $1/n$ to represent the diminishing trend between the pair cities, where n is the quantity of agreements signed between cities i and j. Each city gains half of n and the sum of their products is the government intervention index (GII$_{ij}$), which is obtained using Equation (8) as follows.

$$GII_{ij} = \sum_{1}^{n}\left(\frac{1}{n} \times \frac{1}{2}\right)^2 \tag{8}$$

To test whether our modified model based on the comprehensive transportation distance, function complementarities, and government intervention factors could characterize city contacts better, we entered the comprehensive transportation distance, city function complementarities index, and government intervention index into Equation (2) and obtained the relative (without any real unit) modified city contact. We performed a simple linear regression analysis of the OD results and those obtained using the modified gravity model, based on the three factors in the comprehensively modified results. Finally, we compared the adjusted R^2 value rather than R at a $p < 0.01$ significance level to obtain the final results for the different variables using the two models. A higher adjusted R^2 values indicated the better characterization of the actual city contacts.

3 Results

Using all-the-way and all-city-passenger OD data for PRD and the technical spatial analysis, we mapped the actual city contacts in PRD (Table 1 and Fig. 2).

Table 1 and Fig. 2 show that with a high passenger flow volume of 322 043 people per day in PRD, Guangzhou-Shenzhen (it refers to the passenger flow volume between Guangzhou and Shenzhen, the same below) had a 127 times higher city contact than Zhaoqing-Huizhou, while the city contact between Guangzhou and its surrounding cities was the closest. The city contacts between Guangzhou-Shenzhen, Guangzhou-Dongguan, and Guangzhou-Foshan were the three highest. The city contacts between Guangzhou and other cities in PRD were also higher than the average level in PRD, which supports its status as the capital of Guangdong Province and the core city in PRD. In addition, the city contacts

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① The Year 2009 included a large number of agreements signed among the nine cities in PRD and the start of multi-corporations after the important policy document *the Pearl River Delta Region Reformation and Development Planning Outline* (*2008-2020*) took effect.

Table 1 Actual city contacts based on OD data   (unit: people per day)

City	Guangzhou	Foshan	Zhaoqing	Zhongshan	Jiangmen	Zhuhai	Dongguan	Shenzhen	Huizhou
Guangzhou		255931	70923	86035	188719	68157	256953	322043	46194
Foshan			58496	34372	54581	22847	43239	40994	18190
Zhaoqing				8605	19091	4592	15013	8914	2538
Zhongshan					28020	46234	28179	27709	3797
Jiangmen						56646	40316	37179	11432
Zhuhai							33245	15078	5159
Dongguan								191865	58350
Shenzhen									75461
Huizhou									

Fig. 2   Actual city contacts based on OD data in PRD

between Dongguan-Huizhou-Shenzhen were also relatively close, whereas the city contacts between Zhaoqing-Zhongshan, Zhaoqing-Zhuhai, Zhaoqing-Shenzhen, Zhongshan-Huizhou, and Zhuhai-Huizhou were generally weak, i.e., <10 000 people per day.

Table 2 and Fig. 3 show that the results of the traditional gravity model only reflected the basic framework of the actual city contacts based on the OD data,

whereas the absolute data were clearly smaller than the actual city contacts based on the OD data for PRD. Table 2 shows that city contacts based on traditional gravity model have a bigger difference than OD data, for example, the biggest city contact (13004) is 1445 times than the smallest one (9).

Thus, the traditional gravity model is not suitable for modeling the actual city contacts. Therefore, it is necessary to modify the traditional gravity model to characterize city contacts. After reformulating the model, we found that the factors considered in the traditional gravity model were too limited, with an over-emphasis on a city′s own attributes, whereas the relationships between cities are ignored, such as function complementarities and government intervention elements, thereby yielding only a rough approximation of the city contacts in PRD, as we mentioned above. In addition, the Euclidean distance used in the traditional gravity model was unrealistic because it could not represent the actual inter-city location relationships.

Therefore, we consider that the function complemen-

Table 2 City contacts based on traditional gravity model

City	Guangzhou	Foshan	Zhaoqing	Zhongshan	Jiangmen	Zhuhai	Dongguan	Shenzhen	Huizhou
Guangzhou		13004	223	357	513	109	1763	697	148
Foshan			185	243	479	67	621	349	65
Zhaoqing				25	57	10	48	46	9
Zhongshan					405	207	213	333	27
Jiangmen						74	164	189	23
Zhuhai							85	297	17
Dongguan								1106	241
Shenzhen									349
Huizhou									

Fig. 3 City contacts based on traditional gravity model in PRD

tarities and government intervention elements should be integrated into the traditional gravity model and the modified transportation distance should be used instead of the Euclidean distance.

When considering effects of the market and government, the constant values w_1 and w_2 had no effects on the comparison, so we did not consider the two constant values. Using Equation (2), we calculated city contacts based on three comprehensively modified factors, i.e., the comprehensive transportation distance, functional complementarities, and government intervention factors (with no consideration of the constant value, w_1 and w_2) (Table 3).

Intuitively, we concluded that city contact results modified by these three influencing factors in PRD could also describe the basic frameworks of the actual city contacts based on the OD data. In the simple comparison shown in Table 3, the maximum data is not closer to the actual city contact compared with Table 2, but Table 3 provides a relative visual description of the strongest city contacts, such as the city contacts between Guangzhou-Foshan, Guangzhou-Shenzhen and Dongguan-Shenzhen.

This simple analysis showed that the three factors in the comprehensively modified model characterized the actual city contacts better than the traditional gravity model.

To quantify whether the city contacts modified using these three factors could characterize the city contacts better in PRD, we performed a simple linear regression analysis using the actual OD contacts and the traditional gravity model contacts (1 in Table 4), and another between the actual OD contacts and the modified model contacts (2 in Table 4).

The results indicate that at the $p < 0.01$ significance level (Significance F), the adjusted R^2 of the former was 0.259, whereas that of the latter was higher at 0.379. This result supports the conclusion that the consideration of more factors allowed the modified model to characterize the city contacts more accurately than the traditional gravity model. Thus, the modified model based on these three factors enhanced the description of city contacts in PRD.

One question that remains to be clarified is whether the government intervention factor related to the quantity of agreements might make the results more applicable. While the result of adjusted R^2 for the non-government intervention factor modified model (which only considered the comprehensive transportation and function complementarities factors) was 0.390, a slightly higher than that when the government intervention factor was included, it can not be concluded that the government intervention factor had little effect on city contacts. Indeed, we argue that the government intervention factor will have a vital effect on city contact characterization and because of its importance, the government intervention factor is very complex and hard to quantify (as demonstrated by the results given above). Therefore, it may be necessary to identify a more suitable variable for characterizing city contact in the future.

Table 3 City contacts based on modified gravity model

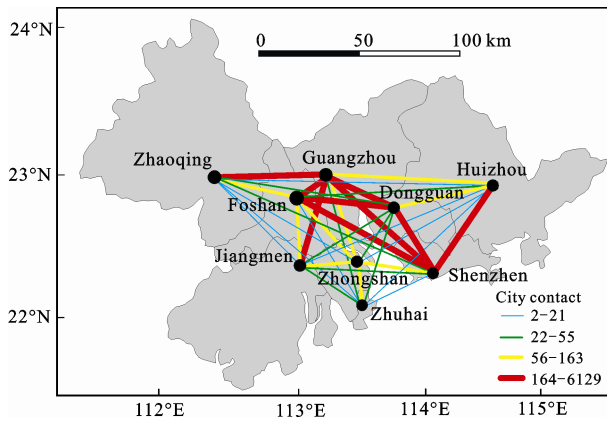| City	Guangzhou	Foshan	Zhaoqing	Zhongshan	Jiangmen	Zhuhai	Dongguan	Shenzhen	Huizhou
Guangzhou		6129	176	161	165	55	977	916	105
Foshan			153	74	163	21	230	219	37
Zhaoqing				5	11	2	33	30	4
Zhongshan					123	80	44	94	9
Jiangmen						25	36	52	6
Zhuhai							30	18	3
Dongguan								1731	128
Shenzhen									164
Huizhou									

Fig. 4　City contacts based on modified gravity model in PRD

Table 4　Some statistic data related to simple linear regression analysis

Regression statistics				
	Multiple R	R^2	Adjusted R^2	Significance F
1	0.529	0.280	0.259	0.001
2	0.630	0.396	0.379	0.000
Coefficients analysis				
		Coefficients	Standard error	t Stat	p-value
Intercept	1	–287	398	–0.720	0.477
	2	–195	178	–1.093	0.282
OD contact	1	0.014	0. 004	3.636	0.001
	2	0.008	0.002	4.725	0.000

Notes: 1 represents a simple linear regression analysis using the actual OD contacts and the traditional gravity model contacts, and 2 represents a simple linear regression analysis using the actual OD contacts and the modified model contacts

4　Conclusions

City contact is affected by the individual social and economic conditions of cities, such as the population scale, economic scale, and other social economic attributes, which are described in the traditional gravity model. While the policy factors such as market factors and government factors among cities also take effect on the interaction within cities. Based on our modified model, we offer the following conclusions.

(1) City contacts were characterized better by using the modified model, which included more relevant factors than the traditional gravity model. At a significance level of $p < 0.01$ (Significance F), the adjusted R^2 of the traditional gravity model results and the actual city contacts based on the OD data was 0.259, whereas the adjusted R^2 of these three factors with the comprehen-

sively modified model and the actual city contacts based on the OD data was 0.379.

(2) The intercity transportation distance was better than the simple Euclidean distance, while the city function complementarities and local government interventions had important effects when characterizing city contacts in PRD.

(3) We modified the traditional gravity model by considering the intercity transportation distance, the city function complementarities index, and local government intervention index to estimate the relative city contacts within the region.

Because of the data acquisition method, this study used the actual intercity passage flow volume as the actual city contacts intensity in PRD, whereas there are many more actual city contacts (because the government intervention factor is too complex to generate suitable variable for its characterization), such as trade links and information function links. Therefore, this was not a complete characterization of the actual city contacts, which may have affected the comparison between the modified model results and the summary of the city contact characteristics. Indeed, city contacts include many factors, so our inclusion of these three factors in the comprehensive modification of the gravity model could not describe them as accurate as possible. It may be possible to solve this problem by studying each factors and dividing them into three categories of contacts with people, materials, and information. Considering each component of these factors clearly using the modified gravity model might allow us to generate a more suitable variable for characterizing the government intervention factors, thereby facilitating a more accurate characterization of city contacts.

References

Anderson J E, 2011. The gravity model. *Annual Review of Economics*, 3(1): 133–160.

Camagni R P, Salone C, 1993. Network urban structures in northern Italy: Elements for a theoretical Framework. *Urban Studies*, 30(6): 1053–1064. doi: 10.1080/00420989320080941

Castells M, 2000. The rise of the network society–The Information Age, Economy, Society and Culture, Volume I. Wiley-Blackwell.

Dai Teqi, Jin Fengjun, 2008. Spatial interaction and network structure evolvement of cities in terms of China′s rail passenger flows. *Chinese Geographical Science*, 18(3): 206–213. doi: 10.1007/s11769-008-0206-2

Derudder B, Witlox F, Taylor P J, 2007. United States cities in the world city network: Comparing their positions using global origins and destinations of airline passengers. *Urban Geography*, 28(1): 74–91. doi: 10.2747/0272-3638.28.1.74

Dobkins, L H, Ioannides Y M, 2001. Spatial interactions among US cities: 1900–1990. *Regional Science and Urban Economics*, 31(6): 701–731. doi: 10.1016/S0166-0462(01)00067-9

Friedman J, 1995. Where we stand: A decade of world city research. In: Knox P *et al.* (eds). *World Cities in a World-system*. New York: Cambridge University Press, 21–47.

Guangdong Development and Reform Commission, 2009. *The Pearl River Delta Region of Integrated Rail Transit Planning* (*modified version*). (in Chinese)

Guo Lijuan, Wang Ruyuan, 2009. Study on accessibility and spatial connecting among the cities in Sichuan Basin urban agglomeration. *Human Geography*, 24(3): 42–48. (in Chinese)

Hesse M, 2010. Cities, material flows and the geography of spatial interaction: urban places in the system of chains. *Global Networks*: *A Journal of Transnational Affairs* (*SI*), 10(1): 75–91.

Krugman, 2002. *Geography and Trade*. Beijing: Peking University Press. (in Chinese)

Liu X J, Taylor P J, 2011. Research note-a robustness assessment of global city network connectivity rankings. *Urban Geography*, 32(8): 1227–1237. doi: 10.2747/0272-3638.32.8.1227

Liu Y B, Cai X, 2009. Modeling economic spatial contact among cities with the intensity and structure model of urban flow. *Applied Computing*, *Computer Science*, *and Advanced Communication*, *Proceedings*, 34: 157–163. doi: 10.1007/978-3-642-02342-2_22

Lukermann F, Porter P W, 1960. Gravity and potential models in economic geography. *Annals of the Association of American Geographers*, 50(4): 493–504. doi: 10.1111/j.1467-8306.1960.tb00364.x

Luo Shougui, Andrew Johnston, Chen Dongchun, 2008. Approach to delimiting metropolitan regions′ boundary and grading urban hierarchy within a metropolitan region—A case study of Shanghai Metropolitan Region. *Chinese Geographic Science*, 18(3): 197–205. doi: 10.1007/s11769-008-0197-z

McArthur D P, Kleppe G, Thorsen I *et al.*, 2011. The spatial transferability of parameters in a gravity model of commuting flows. *Journal of Transport Geography*, 19(4): 596–605. doi: 10.1016/j.jtrangeo.2010.06.014

Meng Deyou, Zhao Wenliang, 2011. Spatial structure of urban economic linkage in He′nan Province based on travel time cost. *Urban Studies*, (6): 104–110. (in Chinese)

National Development and Reform Commission, 2008. *The Pearl River Delta Region Reformation and Development Planning*

Outline (*2008–2020*). (in Chinese)

National Bureau of Statistics of China, 2010. *China City Statistical Yearbook 2009*. Beijing: China Statistics Press. (in Chinese)

Roy J R, Thill J C, 2004. Spatial interaction modeling. *Papers in Regional Science*, 83(1): 339–361. doi: 10.1007/978-3-540-24807-1

Sassen S, 1994. *Cities in a World Economy*. Thousand Oaks, CA: Pine Forge.

Smith D A, Timberlake M, 1995. Conceptualizing and mapping the structure of the world system's city system. *Urban Studies*, 32(2): 287–302.

Statistics Bureau of Guangdong Province, 2009. *Guangdong Statistical Yearbook 2009*. Beijing: China Statistics Press. (in Chinese)

Taylor J, Catalano G, Walker D, 2002. Measurement of the world city network. *Urban Studies*, 39(13): 2367–2376. doi: 10.1080/0042098022000027013

Taylor P J, 2004. *World City Network*: *A Global Urban Analysis*. UK: Psychology Press.

Wu Wenjie, Zhang Wenzhong, Jin Fengjun *et al.*, 2009. Spatio-temporal analysis of urban spatial interaction in globalizing China—A case study of Beijing-Shanghai corridor. *Chinese Geographic Science*, 19(2): 126–134. doi: 10.1007/s11769-009-0126-9

Yan Weiyang, Wang Fazeng, Qin Yaochen, 2009. Analysis of the principle and evolvement of the theoretic models of urban spatial interaction. *Progress in Geography*, 28(4): 511–518. (in Chinese)

Yao Shimou, Wang Shuguo, Chen Shuang *et al.*, 2006. Spatial system of ′urban agglomeration′ in district development. *Economic Geography*, 26(5): 726–730. (in Chinese)

Zbeleznyak O O, Oleshchenko L M, 2011. Applying gravity models in economic research. *Actual Problems of Economics*, 125(11): 269–278.

Zhao Xueyan, Jiang Jinde, Zhang Li *et al.*, 2011. The economic links between the cities in Wanjiang Urban Belt and the radiation scope of the central city. *Economic Geography*, 31(2): 218–223. (in Chinese)

Zhou Huilai, Guo Rui, 2007. A review and prospect on the research of urban agglomeration. *Areal Research and Development*, 26(5): 55–60. (in Chinese)

Zhou Yixing, 1998. Major directions of economic linkages: Some theoretical considerations. *Urban Planning*, (2): 22–26. (in Chinese)

Zhou Yixing, 2003. *Urban Geography*. Beijing: The Commercial Press. (in Chinese)