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Study on Jobs-Housing Spatial Relationship and Commuting Efficiency: Evaluation Potential of Excess Commuting

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Abstract: Excess commuting is an analytical framework for assessing the jobs-housing spatial relationship and commuting efficiency. This paper first reviews the origin and evolution of the concept of excess commuting in the past three decades, and then highlights its strength and weakness when applied to evaluate commuting efficiency. By placing Bertaud's commuting model and its spatial structure in Brotchie's Triangle Model, the paper discusses various evolution directions caused by the change of jobs-housing spatial relationship. The paper also analyzes the potentials of excess commuting in assessing urban jobs-housing balance and commuting efficiency. The paper concludes that the excess commuting framework is an important analysis tool for studying the transformation of urban spatial form and evaluating the optimization of spatial structure. **DOI:** 10.13813/j.cn11-5141/u.2018.0202-en

Keywords: jobs-housing spatial relationship; excess commuting; commuting efficiency; urban form and structure

0 Introduction

Rapid urbanization has led to profound changes in the jobs-housing spatial relationship in China's large cities, and some urban problems such as long commuting and traffic congestion have also emerged. In the past 10 plus years, Chinese scholars have been studying urban jobs-housing spatial relationship and associated commuting phenomenon by constructing different research frameworks and models from multiple perspectives [1–10], and furthermore exploring the underlying mechanism, with the goal to propose corresponding planning strategies. Beyond conducting case studies on large cities in China, Chinese scholars also focused on the review of the methods and frameworks based on the western urban spatial research network. Reference [11] reviewed research on jobs-housing balance, and Reference [4] reviewed the spatial mismatch hypothesis and its research methods. These reference reviews clarified the concepts, summarized the logics and thoughts, and laid solid foundations for the research in China. However, the research on the methods and progress of excess commuting is still less. Only several studies can be found to study the jobs-housing spatial relationship in Chinese cities in the framework of excess commuting, including References [12–14].

As an analytical framework for assessing the jobs-housing spatial relationship, excess commuting has been applied by more and more scholars. Since it was initiated 30 years ago, excess commuting has made substantial progress. Several commuting definitions and indices were proposed, and excess commuting gradually became a research model to evaluate cities' jobs-housing balance and commuting efficiency. Since many scholars and planners empirically attributed the increasingly severe traffic congestion in large cities in China to the jobs-housing imbalance, it is critical to conduct a systematic review of excess commuting, which focuses on jobs-housing relationship in spatial configuration and commuting efficiency.

This paper is organized as follows. The first section reviews the key references in a chronological order and sorts out the entire process of the origin and evolution of excess commuting. Different commuting models based on Brotchie's Triangle Model were analyzed and Bertaud's urban spatial structure was verified in the second section. The third section focused on the potential significance of excess commuting on the study of Chinese cities' urban spatial structure.

1 Research framework of excess commuting

1.1 The establishment of basic concepts

Excess commuting is a research framework that was

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initiated by urban economists to analyze the urban jobs-housing spatial relationship and its commuting efficiency. This paper conducts a chronological review of the establishment of excess commuting and its evolution to help accurately recognize its evaluation potential.

According to Alonso's monocentric city model, References [15–16] assumed that all jobs are located at the center of a city and there are no differences in the utilities of commuting and choosing house locations. Then References [15–16] compared the theoretical and actual average commuting distances to examine the effectiveness of Alonso's model. In a case study of 14 American metropolitan areas and 27 Japanese cities, it was found that the actual commuting distance is about eight times the theoretical value predicted by the monocentric model, and their differences are theoretically insignificant, thus being defined as ''wasteful commuting''. As a new concept to illustrate the commuting efficiency, wasteful commuting immediately spurred the interests of many scholars who actively conducted research on this topic. In the beginning, most discussions focused on whether the monocentric model could appropriately simulate the actual urban spatial structure [17–18], and whether it could accurately predict the actual urban commuting behaviors. For example, Reference [19] pointed out that the ideal monocentric model is inconsistent with the actual spatial structure of a metropolitan area, and a polycentric model can model actual commuting behaviors more reasonably and effectively. Reference [20] questioned the calculation method used in References [15–16]. It demonstrated that the assumption of all jobs located at the center of a city is unnecessary for the calculation of the theoretical minimum average commuting distance. Instead, this distance can be calculated by minimizing the total transportation cost in the linear programming function, with the constraint of the numbers of residents, employees and commuters being equal. This method is called transportation problem in linear programming (TPLP) method. The difference between the theoretical minimum and actual average commuting distances can then be defined as excess commuting. The formula to calculate the theoretical minimum average commuting distance is listed in Formula (1):

$$T_{\min} = \frac{1}{W}\sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}X_{ij} \ , \qquad (1)$$

In Formula (1), $T_{\min}$ is the minimum average commuting distance; W is the total number of commuters; X_{ij} is the number of commuters from zone i to zone j to minimize the total commuting cost; c_{ij} is the commuting distance between zones i and j; and n and m are the total number of housing areas and the total number of job areas, respectively.

The constraints for Formula (1) are as follows:

$$\sum_{i=1}^{n} X_{ij} = O_i, \ \forall i = 1, 2, \cdots, n \ , \qquad (2)$$

$$\sum_{j=1}^{m} X_{ij} = D_j, \ \forall i = 1, 2, \cdots, m \ , \qquad (3)$$

$$O_i = D_j \ , \qquad (4)$$

where, O_i is the number of commuters living in zone i, and D_j is the number of jobs in zoen j.

When X_{ij} represents the actual number of commuters from zone i to j, Formula (1) calculates the actual average commuting distance T_{act}, and then the index of excess commutingrate C_{ex} can be constructed as Formula (5):

$$C_{ex} = \frac{T_{\text{act}} - T_{\min}}{T_{\text{act}}} \times 100\% \ . \qquad (5)$$

Reference [21] argued that the excess commuting rate calculated by Formula (1) still had many deficiencies in evaluating the commuting efficiency and the jobs-housing spatial relationship in a city: It is significantly affected not only by modifiable areal units [21], but also by the city size [22]. When comparing two cities with different sizes, equal excess commuting rates calculated using Formula (1) do not necessarily indicate the commuting efficiency of both cities is the same. Obviously, the commuting efficiency in the larger city is higher than that in the smaller one. Therefore, Reference [22] proposed another new term, maximum average commuting distance $T_{\max}$ to expand the research framework of excess commuting. It argued that the urban commuting efficiency should be determined by the relative closeness of the actual average commuting distance (in the form of percentage) between the minimum average commuting distance (lower limit) and the maximum average commuting distance (upper limit)①. The index of commuting potential utilized was also constructed:

$$C_u = \frac{T_{\text{act}} - T_{\min}}{T_{\max} - T_{\min}} \times 100\% \ . \qquad (6)$$

In the theoretical maximum average commuting mode, jobs were matched to housing locations to maximize the total commuting cost, without changing the jobs-housing spatial distribution. The lower the commuting potential utilized, the higher the urban commuting efficiency. When calculating the theoretical maximum average commuting distance $T_{\max}$, the TPLP method can still be used because:

$$\max\left(\sum_{i=1}^{n}\sum_{j=1}^{m} c_{ij}X_{ij}\right) \equiv \left|\min\left(\sum_{i=1}^{n}\sum_{j=1}^{m} -c_{ij}X_{ij}\right)\right| . \qquad (7)$$

Using the theoretical maximum average commuting distance to measure the excess commuting rate was questioned by Reference [23], because the hypothesis of maximizing the total commuting cost is contrary to the economic theory of cost minimization, and it is only an external extremum of many commuting distance distribution models. Reference [23] believed that it is more reasonable to measure the urban commuting efficiency using a random average commuting distance T_{rand} instead of the maximum average commuting distance. The random commuting distance is the average commuting distance when all commuters are assumed not to consider commuting distances while choosing jobs. Reference [23] proposed two calculation methods: the maximum entropy method and the Monte Carlo simulation. The maximum entropy method requires a large number of random samples, which is very difficult in practice. The second method is relatively simple, and the formula is as follows:

$$T_{\text{rand}} = \frac{1}{W^2}\sum_{i=1}^{n}\sum_{j=1}^{m} O_i D_j X_{ij} . \quad (8)$$

In the second year after Reference [23] was published, Reference [24] proposed the concept of proportionally matched commuting (PMC). With PMC, the proportion of any jobs in zone *j* assigned to a residential zone *i* is proportional to the share of jobs in zone *j* in the entire region's labor market. So the commuting flow of PMC is calculated as:

$$X_{ij} = \frac{D_j}{\sum_j D_j} O_i . \quad (9)$$

Substituting Formula (9) into Formula (1), it can be shown after some mathematical deviations that the formula to calculate the average commuting distance in accordance with the PMC model is equivalent to that in accordance with the random commuting model using the Monte Carlo simulation [25].

Based on the concept of random average commuting distance proposed by Reference [24], Reference [26] put forward two distinct excess commuting indices: commuting economy (C_e) and normalized commuting economy (C_{Ne}). The commuting economy was introduced to measure the cost savings of the actual commuting mode relative to the random commuting mode. A larger commuting economy value indicates more commuting costs are saved and the commuting efficiency is higher. Normalized commuting economy was introduced to measure the proportion of the excess commuting (the difference between the actual and the minimum average commuting distances) to the commuting potential (the difference between the random and the theoretical minimum average commuting distances). A smaller normalized commuting economy value indicates that the actual average commuting distance is closer to the theoretical minimum commuting distance, the commuting potential utilized is lower, and the commuting savings are higher. The formulas for the two indices are as follows:

$$C_e = \frac{T_{\text{rand}} - T_{\text{act}}}{T_{\text{rand}}} \times 100\% , \quad (10)$$

$$C_{Ne} = \frac{T_{\text{act}} - T_{\text{min}}}{T_{\text{rand}} - T_{\text{min}}} \times 100\% . \quad (11)$$

So far, based on the four basic concepts and the four indices of commuting efficiency, the overall framework to study excess commuting is basically completed. Fig. 1 clearly represents the relationship among these concepts and indices, and makes them easy to understand.

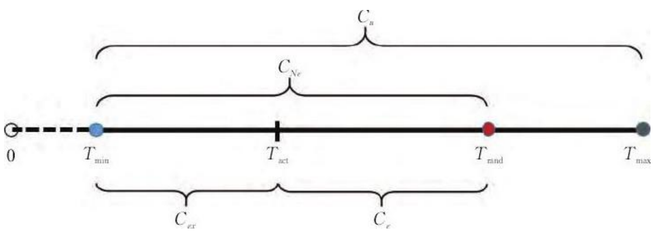

Fig. 1 Schematic representation of concepts and indices in the excess commuting framework

1.2 The interpretation potential of indices

There are four basic concepts in the framework of excess commuting: the actual average commuting distance T_{act}, the theoretical minimum average commuting distance T_{min}, the theoretical maximum average commuting distance T_{max} and the random average commuting distance T_{rand}. They all describe commuting modes in which each job is matched to a resident, with the given spatial distribution of jobs and housing. Among the four concepts, the theoretical minimum commuting, the theoretical maximum commuting and the random commuting are all fictitious, and they are introduced to measure the commuting efficiency of a city by comparing with the actual commuting. An implicit premise is that jobs and housing can be exchanged or replaced indiscriminately without considering the commuters' own socio-economic characteristics and the jobs' types and requirements. Then given spatial distribution of jobs and housing, jobs are spatially matched to housing based on certain rules: The minimum commuting is to minimize the total commuting cost, the maximum commuting is to maximize the total commuting cost, and the random commuting is to match randomly without considering commuting costs. The actual average commuting distance is an observed value that reflects the actual commuting behaviors under the actual spatial correspondences between jobs and housing. It is a combination of various factors, such as the matching of commuters' own socio-economic characteristics and jobs' types and requirements, the distribution of transport facilities and the degree of commuters' access to employment information.

The theoretical minimum commuting is to match jobs to the closest housing, and it reflects the degree of jobs-housing balance, that is how far to travel on average to get a job. A smaller value indicates a potentially higher degree of jobs-housing balance, and a larger value indicates a lower degree. This is more reasonable than statically determining the degree of jobs-housing balance by comparing the number of jobs and commuters (that is, the ratio of jobs to housing) in a zone②.

The theoretical maximum average commuting distance is to measure the commuting mode dominated by cross-city traffic. Its value is mainly affected by the size of a city: The larger the city size, the larger the value. Together with the theoretical minimum average commuting distance, they constitute the upper and lower limits in the calculations of excess commuting, and both the actual and the random commuting distances fall within this range. According to an empirical study of more than 30 cities in Canada [25], the theoretical maximum average commuting distance is highly correlated to the random commuting distance (R = 0.99), and the ratio is relatively stable at about 1.28. Therefore, when measuring excess commuting or comparing commuting efficiencies, it is both theoretically and empirically logical to replace the theoretical maximum average commuting distance with the random commuting distance.

The four secondary indices: excess commuting rate (C_{ex}), commuting economy (C_e), normalized commuting economy (C_{Ne}) and commuting potential utilized (C_u) are used to describe the commuting efficiency from different perspectives, with the given jobs-housing spatial distribution pattern. The excess commuting rate compares the difference between the actual commuting and the theoretical minimum commuting, and measures the reduction in actual commuting when adjusting the spatial correspondence between jobs and housing. The commuting potential utilized measures the excess commuting as a proportion of the commuting distance range defined by the theoretical minimum and maximum commuting distances. It takes into account the city size, and therefore can be used for horizontal comparisons of commuting efficiencies in cities of different sizes. The commuting economy explains the degree of residents' optimization in matching jobs and housing, in relative to random matching. It implicitly indicates the residents' savings in transportation costs of commuting behaviors. The normalized commuting economy is similar to the commuting potential utilized, but it measures the commuting behaviors (already considered cost savings) as a proportion of the commuting distance range defined by the theoretical minimum and the random commuting distances, and it focuses on the magnitude of commuting cost savings.

1.3 Vertical comparison of changes in actual commuting distances

In a given urban form and spatial structure, the theoretical minimum, the theoretical maximum, and the random average commuting distances are all fixed. Meanwhile, the residents' jobs-housing spatial relationship and their commuting behaviors are a response to the established urban environment. Without changing the urban form, the actual commuting distance can be shifted to the left or to the right (Fig. 1) if it is affected by certain socio-economic policies (e.g., reducing jobs search costs, reducing housing replacement costs, and reducing travel costs). The extent of left and right movements can reflect the effectiveness of a policy in influencing the efficiency of urban commuting. So, Reference [30] proposed a measurement method to diagnose whether the commuting efficiency has been optimized. Based on the spatial interaction model, an index was developed to measure the effort to reduce the actual commuting distance of a city to a preset level. For an established urban form, the entropy of the actual commuting distance is first calculated, the entropy of the reduced commuting distance is then calculated, and the difference between the two is the effort to reduce the actual commuting distance to a predetermined commuting distance. The formulas to calculate entropy are as follows:

$$H = -\sum_i \sum_j X_{ij} \ln X_{ij} \text{ ,} \tag{12}$$

$$E = H_1 - H_2 \text{ ,} \tag{13}$$

In Formula (13), H_1 is the entropy for the actual commuting distance and H_2 is the entropy for the reduced commuting distance. By comparing the entropy before and after reducing the actual commuting distance, this index measures the degree of effort required to reduce the actual commuting distance. This index does not consider the specific values of the theoretical minimum, the theoretical maximum, and the random average commuting distances. It only reflects the effort required to adjust the jobs-housing spatial correspondence given the existing urban form (Fig. 2, from commuting mode A to commuting mode B), which is the effectiveness that can be achieved by a non-spatial planning policy.

In summary, it is appropriate to use different concepts and indices to evaluate certain aspects of urban commuting efficiency. The minimum average commuting distance ($T_{\min}$) is used when determining whether the spatial distribution of jobs-housing is balanced. The excess commuting rate (C_{ex}) is used when investigating whether commuting behaviors match with the urban form. The normalized commuting economy (C_{ne}) and the commuting potential utilized (C_u) are used to measure how the residents' commuting behaviors respond to the separation and scattered distribution of jobs and housing. The commuting economy (C_e) is used when evaluating the impact of commuting distance on the choice of residents' jobs and housing locations. And the index "effort" is used when reducing the actual commuting distance and measuring the flexibility of the existing urban form.

The above reference reviews summarize the studies on the explanation potential of excess commuting, and all the studies are based on the hypothesis of the "established jobs-housing spatial distribution structure and pattern". It requires further exploration to study what evolutionary trend excess commuting will present if the jobs-housing spatial distribution changes. Although References [25, 31] reviewed and summarized existing studies, and they did not discuss much detail about the relationship between excess commuting and the urban form and structure. The following chapter is motivated to fulfill this research gap.

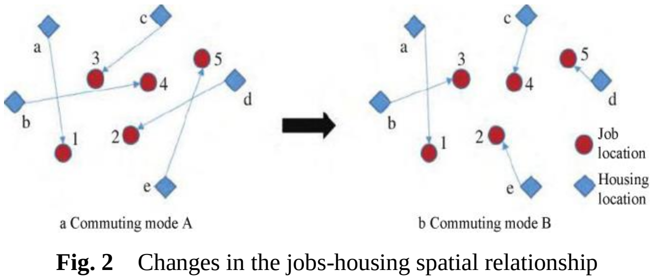

Fig. 2 Changes in the jobs-housing spatial relationship

2 Excess commuting metrics under different spatial structures

As a carrier of social and economic activities, cities will inevitably undergo spatial changes with socio-economic development and transformation, such as the expansion of urban areas and the spatial redistribution of job and housing activities. Many scholars have conducted research on how the spatial structure evolves, what is the direction of evolution, whether the theoretical minimum commuting distance increases or decreases, and how the actual average commuting distance changes.

2.1 Brotchie's Triangle Model

The study of urban commuting mode under different urban spatial forms and structures has been the main topic of urban geography and urban economics. Reference [31] for the first time used the Brotchie's Triangle Model to analyze excess commuting under different urban spatial structures and simulated the corresponding excess commuting indicators of the four commuting modes under various scenarios. Reference [32] has applied the Brotchie's Triangle Model to the horizontal and vertical empirical comparisons of three cities and three time points in Canada.

The Brotchie's Triangle Model proposed by Reference [33]was a research framework originally used to analyze urban decentralized development and travel mode under the reform of traffic technology. This framework can provide useful insights when analyzing the relationship between urban spatial structure changes and residents' travel behaviors. Fig. 3 is a diagram of Brotchie's Triangle Model, which shows the relationship between the dispersion degree of land use and travel distance. The horizontal axis shows the extent of land use dispersion, and the synergy degree of jobs and housing dispersion (see Formula (14) for the calculation of *x*): 0 means that all jobs are concentrated at the city center, and 1 means that jobs and housing activities are decentralized and they are matched exactly③. The vertical axis represents the travel distance: 0 represents the travel distance is right at 0, and D represents the diameter of the urban built-up area, that is, the maximum travel distance when all jobs-housing activities are evenly distributed with a certain density. For cities with similar number of commuters, the smaller the average jobs (housing) density, the larger the *D*.

$$x = \frac{\frac{1}{E}\sum_j d_j e_j}{\frac{1}{H}\sum_j d_j h_j}, \qquad (14)$$

In Formula (14), x is the synergy degree of jobs and housing dispersion; E is the total number of jobs; e_j is the number of jobs in zone j; H is the total number of residents; h_j is the number of residents living in zone j; and d_j is the distance (in km) from the city center to zone j. If it is a study in which each resident has a matching job, there is $H = E$.

Among the three vertices of the triangle, Point A represents the average travel distance when all jobs are at the city center, and the corresponding travel distance of A is about the radius of the built-up area. Point B indicates that job and housing activities are completely dispersed. The residents' choice of jobs and housing locations does not consider transportation costs, and all commuters choose the farthest jobs; therefore, the commuting distance is the largest at Point B. Point C means that all commuters choose the nearest jobs so that the transportation cost is the lowest. Segment BC is perpendicular to the horizontal axis and represents the impact of travel cost on the average commuting distance. At Point C, the commuting cost is infinite, so all commuters choose the nearest jobs and make the average commuting distance the minimum. At Point B, the impact of travel cost on the commuting distance is zero, and all commuters choose the farthest jobs, which contributes to the maximum commuting distance. For all the commuting distances between Point B and Point C, the closer to Point C, the greater the impact of travel costs on the actual commuting distance. The three vertices A, B and C respectively represent three extreme commuting patterns under three different spatial structures of a city, and the actual urban commuting pattern must fall in the triangle region.

2.2 Analysis of excess commuting within Brotchie's Triangle Model

When Fig. 1 is rotated 90° counterclockwise and then moves to segment BC in Fig. 3, the four points of the vertical line can represent the average commuting distances corresponding to the four commuting modes under a certain spatial form (see Fig. 4). As mentioned in the first chapter, under the established jobs-housing spatial distribution, the theoretical maximum, the theoretical minimum, and the random average commuting distances are also fixed. The movement (increase or decrease) of actual average commuting distance reflects the direction and extent of the impact of transportation costs on commuting distances. This triangle model can be used to discuss the changes in excess commuting under different jobs-housing distribution patterns and spatial structures.

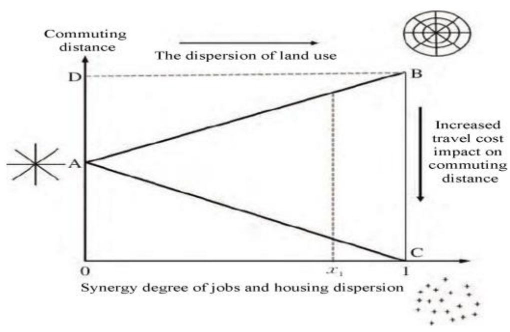

Fig. 3 Brotchie's Triangle Model

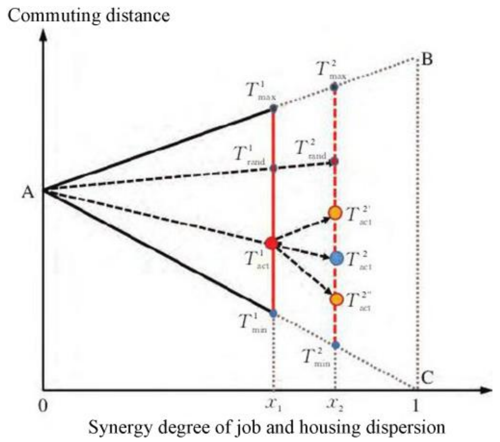

Fig. 4 Analysis of excess commuting based on Brotchie's Triangle Model

In Fig. 4, if the size of the city's jobs (residents) is constant (the triangle ABC is constant), and the jobs-housing spatial distribution and structure change from Scenario 1 (x_1) to Scenario 2 (x_2), the following analyses can be made:

1) When $x_2 > x_1$, the synergy degree of jobs-housing spatial distribution is improving, and the commuting potential capacity ($T_{max}-T_{min}$) is increasing, which means the diversity of matching jobs and housing activities is also increasing.

2) When $T^2_{min} < T^1_{min}$, the minimum commuting distance is decreasing, which means that the possibility of jobs-housing balance is increasing from the quantitative point of view.

3) In Scenario 2, as analyzed above, if the actual commuting distance evolves from $T^{2'}_{act}$ to T^2_{act}, non-spatial socio-economic policies (such as lowering housing replacement costs or increasing travel costs) reduce the actual average commuting distance by affecting residents' choices on jobs and housing locations, and the efficiency of urban commuting has been improved.

4) The change of the actual commuting distance has many possibilities, from T^1_{act} to T^2_{act}, $T^{2'}_{act}$ or $T^{2''}_{act.}$ When it evolves from T^1_{act} to $T^{2'}_{act}$, the evolution of spatial forms causes an increase in the actual commuting distance. If it evolves from T^1_{act} to T^2_{act} or $T^{2''}_{act}$, the evolution of spatial forms causes a decrease in the actual commuting distance, but the magnitude is different. If it falls to T^2_{act}, the excess commuting rate (C_e) of Scenario 2 is greater than that of Scenario 1. To maintain the excess commuting rate for Scenario 1, the actual average commuting distance must drastically drop to $T^{2''}_{act}$.

2.3 Spatial structure and travel mode in Brotchie's Triangle Model

Brotchie's Triangle Model is a useful analytical tool to help understand urban spatial structure and residents' travel modes comprehensively and profoundly, and it can provide accurate insights on spatial forms and structures. This paper discusses the Bertaud's urban spatial structure and travel mode proposed in Reference [34] within the Brotchie's Triangle Model (see Fig. 5).

It is assumed that the housing locations are evenly distributed in the built-up areas with a certain density, and the spatial distribution of all jobs can be classified into three situations: monocentric, acentric and polycentric. For the monocentric structure of jobs (see Point A in Fig. 5), all commuter trips are centripetal, and the spatial structure and travel mode are represented by graph *a*. When the spatial structure of jobs spreads out from a single center outward until job activities are also distributed evenly as housing activities, there are two modes. One is to spread along the line AB, which means that most commuters are commuting through the city and residents commute to the farthest jobs. This travel mode is represented by graph *b*. The other is to spread along the line AC, which means that most commutes choose the nearest jobs to minimize the commuting cost, and the average commuting distance is close to the minimum. This travel mode is represented by graph *c*.

Different polycentric patterns emerge while jobs spread out to different extents. In this paper, it is assumed for the demonstration purpose that there are two kinds of synergy between the spatial distribution of job and housing activities. When $x = 0.5$, T_{min} is relatively large; T_{max} is relatively small; the jobs-housing balance is low; the commuting potential ($T_{max}-T_{min}$) is small; and the excess commuting rate is low. The spatial structure and travel mode for $x = 0.5$ is represented by graph *d*. When $x = 0.8$, T_{min} declines, T_{max} increases, and the jobs-housing balance, as well as the commuting potential, increases. The spatial structures and travel modes are represented by graphs *e* and *f*. In the case of graph *e*, there are many cross-city commuting trips, so the actual commuting distance increases and the excess commuting rate rises quickly. In the case of graph *f*, traffic organization is better, residents choose the nearest jobs, and the actual average commuting distance decreases. However, it cannot be determined whether the excess commuting rate rises or falls, which depends on the specific jobs-housing spatial correspondence.

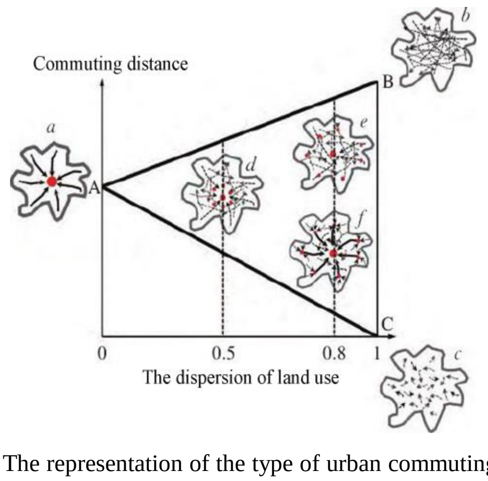

Fig. 5 The representation of the type of urban commuting spatial structure

In summary, when applying the research framework of excess commuting to assess whether the transformation of urban spatial structure has reduced the average commuting distance, the following points need to be noticed to ensure correct analyses.

1) Changes in city size and population density. When the urban population grows, one growth mode is to maintain the original density and to enlarge the urban areas. In this mode, Point A of the Brotchie's Triangle Model moves up, and the maximum average commuting distance also increases. The other growth mode is to keep the urban area unchanged, and to accommodate the new population by increasing the population density. In this mode, Point A and the maximum average commuting distance both remain unchanged.

2) If the population size and density do not change but the jobs-housing spatial distribution has changed, the synergy degree of jobs-housing spatial distribution must be considered, and the excess commuting rate could potentially increase with the increased synergy degree of jobs-housing spatial distribution.

3) The synergy degree of jobs-housing spatial distribution determines the jobs-housing balance. The spatial one-to-one correspondence is affected by non-spatial socio-economic factors, which in turn affects the actual average commuting distance.

3 Conclusion

Urban spatial structure is the most important concept in urban geography and planning. Few previous studies have been found to intensively discuss the spatial structure based on commuting flow and the potential excess commuting. In this paper, these two highly abstract morphological concepts are put together to discuss their interrelationship and the complexity of what they can reveal. However, excess commuting is still the most important research framework for China's jobs-housing imbalance study during the transition of socio-economic development and rapid urbanization. It not only helps accurately assess the existing jobs-housing spatial relationship and the potential degree of jobs-housing imbalance, but also provides a clear picture of what various measures can achieve. For example, excess commuting can be used to analyze the potential of redistributing jobs-housing spatial forms through planning, and the efforts required to adjust jobs-housing spatial correspondence by implementing certain socio-economic policies (reducing jobs search costs, reducing housing replacement costs, and reducing travel costs)

Jobs-housing balance is usually one of the goals in urban-rural master plans. In the period when the urban spatial forms and structures are still undergoing dramatic changes, the achievement of this goal requires an analysis of the jobs-housing spatial relationship and the commuting situation, and proposing corresponding solutions to address the issues found in the analysis. For example, the research framework of excess commuting has the evaluation potential to analyze whether to regulate by land use planning or to adjust through market mechanisms.

Excess commuting has great potential for assessing the jobs-housing balance in the field of urban jobs-housing relationship. It must be noted that for more than 30 years after the concept was proposed, to make it more analytical and interpretive, many scholars have continuously presupposed different assumptions on the basis of their predecessors. On one hand, these presuppositions make the excess commuting framework more comprehensive in theoretical explanation; on the other hand, the separation between theory and reality increases due to the increase of presuppositions. For example, excess commuting investigates individual commuters, while the reality is that a family is one commuting unit and both husband and wife could be employed. Then how to measure the separation of jobs and housing in this case? Another example is that there are different types of jobs, and some commuters have multiple jobs and workplaces. Then how to measure the jobs-housing relationship in this case? In addition, how to investigate more and more flexible commuters who can work from home due to the development of information technology? All these questions provide space for researchers to improve the framework, and also point out the directions for future research.

① The difference between the maximum average commuting distance (T_{max}) and the minimum average commuting distance (T_{min}) is defined as the commuting potential.

② Planners represented by Robert Cervero usually adopt jobs-housing ratio (that is, the ratio of the number of jobs to commuters in a given geographic area) to determine the degree of jobs-housing balance in a city. It is believed that when the ratio is between 0.8 and 1.2, the area is considered to be balanced. According to this method, the geographical scope becomes the key to determining the jobs-housing balance [27–28]. The larger the scale, the higher the degree of balance; the smaller the scale, the lower the balance and the self-sufficiency; that is, the results vary greatly depending on different geographical scales. Therefore, some scholars proposed three levels of measurement: macroscopic, mesoscopic, and microscopic [29]. This metric method is greatly affected by the modifiable areal unit, because in a larger statistical area, even if the jobs-housing balance is high, the actual commuting distance may be large; and in a smaller statistical area, the low degree of jobs-housing balance does not necessarily mean that the actual average commuting distance is large. It is inappropriate to measure jobs-housing balance using jobs-housing ratio, which statically studies the ratio of jobs to residents in a statistical area to evaluate the jobs-housing spatial relationship, and does not take into consideration the commuting behaviors.

③ In a city that aims for agglomeration economic effects, in theory, the degree of dispersion of jobs is less than that of housing. Therefore, the value of "x" will not be greater than 1. The situation where the value of "x" is greater than 1 will only occur in the cities before the industrial revolution or in rural areas.

References

[1] Zhou Suhong, Yan Xiaopei. Characteristics of Jobs-Housing and Organization in Guangzhou [J]. Scientia Geographica Sinica, 2005, 25(6):

664–670 (in Chinese).
[2] Song Jinping, Wang Enru, Zhang Wenxin, et al. Housing Suburbanization and Employment Spatial Mismatch in Beijing [J]. Acta Geographica Sinica, 2007, 62(4): 387–396 (in Chinese).
[3] Meng Bin. The Spatial Organization of the Separation between Jobs and Residential Locations in Beijing [J]. Acta Geographica Sinica, 2009, 64(12): 1457–1466 (in Chinese).
[4] Liu Zhilin, Wang Maojun. Job Accessibility and Its Impacts on Commuting Time of Urban Residents in Beijing:From a Spatial Mismatch Perspective [J]. Acta Geographica Sinica, 2011, 66(4): 457–467(in Chinese).
[5] Sun Bindong, Li Nanfei, Song Jiejie, et al. AStudy on the Impact of Job-Housing Balance on Commuting Travels: An Empirical Test of a Traditional Idea in the Field of Urban Planning [J]. Urban Planning Forum, 2010(6): 55–60 (in Chinese).
[6] Liu Zhilin, Zhang Yan, Chai Yanwei. Home-Work Separation in the Context of Institutional and Spatial Transformation in Urban China: Evidence from Beijing Household Survey Data [J]. Urban Studies, 2009, 16(9): 110–117(in Chinese).
[7] Chai Yanwei, Zhang Yan, Liu Zhilin. Spatial Differences of Home-Work Separation and the Impacts of Housing Policy and Urban Sprawl: Evidence from Household Survey Data in Beijing [J]. Acta Geographica Sinica, 2011, 66(2): 157–166(in Chinese).
[8] Lu Huapu, Ding Yu, Zhang Yongbo. Urban Job-Housing Balance in China:Empirical Analysis and Countermeasures [J]. Urban Transport of China, 2013, 11(3): 1–6 (in Chinese).
[9] Zheng Siqi, Xu Yangfei, Zhang Xiaonan, et al. Jobs-Housing Balance Index and Its Spatial Variation: A Case Study in Beijing [J]. Journal of Tsinghua University (Science and Technology), 2015, 55(4): 475–483(in Chinese).
[10] Zhang Chun, Yi Chengdong, Song Yan. Characteristics of Job-Housing Spatial Relationship and Changes in Beijing:An Empirical Study Based on Data from the 5th, 6th Population Census and Economy Census in 2001 and 2008 [J]. City Planning Review, 2016, 40(10): 59–64 (in Chinese).
[11] Meng Xiaochen, Wu Jing, Shen Fanbu. The Study Review of Urban Jobs-Housing Balance [J]. Urban Studies, 2009, 16(6): 23–28 (in Chinese).
[12] Liu Wangbao, Yan Xiaopei, Fang Yuanping, et al. Related Characteristics and Mechanisms for Excess Commuting in Guangzhou [J]. Acta Geographica Sinica, 2008, 63(10): 1085–1096 (in Chinese).
[13] Zhou Jiangping, Chen Xiaojian, Huang Wei, et al. Jobs-Housing Balance and Commute Efficiency in Cities of Central and Western China: A Case Study of Xi’an [J]. Acta Geographica Sinica, 2013, 68(10): 1316–1330 (in Chinese).
[14] Yang Chao, Wang Chao. Excess Commuting and Jobs-Housing Balance Model [J]. Journal of Tongji University (Natural Science), 2013, 41(11): 1712–1716 (in Chinese).
[15] Hamilton B W, Röell A. Wasteful Commuting [J]. Journal of Political Economy, 1982, 90(5): 1035–1053.
[16] Hamilton B W. Wasteful Commuting Again [J]. Journal of Political Economy, 1989, 97 (6): 1497–1504
[17] Cropper, M L and Gordon, P L. Wasteful Commuting: A Re-Examination [J]. Journal of Urban Economics, 1991, 29 (1): 2–13.
[18] Thurston L, Yezer A M J. Testing the Monocentric Urban Model: Evidence Based on Wasteful Commuting [J]. Real Estate Economics, 1991, 19 (1): 41–51.
[19] Small K A, Song S. “Wasteful” Commuting: A Resolution [J]. Journal of Political Economy, 1992, 100(4): 888–898.
[20] White M J. Urban Commuting Journeys Are Not “Wasteful” [J]. Journal of Political Economy, 1988, 96(5): 1097–1110.
[21] Horner M W. Extensions to the Concept of Excess Commuting [J]. Environment and Planning A, 2002, 34(3): 543–566.
[22] Horner M W, Murray A T. Excess Commuting and the Modifiable Areal Unit Problem [J]. Urban Studies, 2002, 39(1): 131–139.
[23] Charron M. From Excess Commuting to Commuting Possibilities: More Extension to the Concept of Excess Commuting [J]. Environment and Planning A, 2007, 39(5): 12381254.
[24] Yang Jiawen, Ferreira J. Choices Versus Choice Sets: A Commuting Spectrum Method for Representing Job-Housing Possibilities [J]. Environment and Planning B: Planning and Design, 2008, 35(2): 364–378.
[25] Kanaroglou P S, Higgins C D, Chowdhury T A. Excess Commuting: A Critical Review and Comparative Analysis of Concepts, Indices, and Policy Implications [J]. Journal of Transport Geography, 2015, 44: 13–23.
[26] Murphy E, Killen J E. Commuting Economy: An Alternative Approach for Assessing Regional Commuting Efficiency [J]. Urban Studies, 2011, 48(6): 1255–1272.
[27] Cervero R. Jobs-Housing Balancing and Regional Mobility [J]. Journal of the American Planning Association, 1989, 55(2): 136–150.
[28] Cervero R. Jobs-Housing Balance Revisited: Trends and Impacts in the San Francisco Bay Area [J]. Journal of the American Planning Association, 1996, 62(4): 492–5111.
[29] Peng Zhongren. The Jobs-Housing Balance and Urban Commuting [J]. Urban Studies, 1997, 34(8): 1215–1235.
[30] O'Kelly M E, Niedzielski M A. Efficient Spatial Interaction: Attainable Reductions in Metropolitan Average Trip Length [J]. Journal of Transport Geography, 2008, 16(5): 313–323.
[31] Ma K R, Banister D. Urban Spatial Change and Excess Commuting [J]. Environment and Planning A, 2007(39): 630–646.
[32] Chowdhury T A, Scott D M, Kanaroglou P S. Urban Form and Commuting Efficiency: A Comparative Analysis across Time and Space [J]. Urban Studies, 2013, 50(1): 191207.
[33] Brotchie J F . Technological Change and Urban Form [J]. Environment and Planning A, 1984(16): 583–596.
[34] Bertaud A. Note on Transportation and Urban Spatial Structure[R/OL]. 2002[201707-20]. http://www. alain-bertaud. com/images/AB_Transportation_and_Urban_Spatial_ Structure_revised2. pdf.