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An Integrated Land Use and Transport Model to Examine Polycentric Policies of Beijing

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Abstract: Beijing's fast urban growth has caused serious traffic congestion and great environmental damage. The government plans to develop sub-centres in its metropolitan area to ease the pressures associated with being a sole, centralized city service provider. This has been formalized in its recently published master plan, the 'Beijing City Master Plan (BCMP), 2004-2020' (BCMP), which targets the formation of the city plan up to 2020. This study develops a general land-use and transport interaction model to forecast the housing rent distribution based on the present land-use policies and examines whether the objective of decentralized multi-centres can be achieved based on a 'business as usual' scenario. Modelling results show that as of 2020 there will be no sub-centres formed around urban Beijing. Some zones demonstrate the potential to become sub-centres with higher rent increases than the surrounding zones. However, the distribution of these potential zones has a different spatial pattern from what the master plan anticipates. This work may well provide a modelling tool for China's decision makers to examine land-use policies before putting them into practice.

1. INTRODUCTION

China is undergoing rapid and large-scale urban expansion ([Jiang, Deng, & Seto, 2012](#); [Liu et al., 2012](#); [Gu & Pang, 2009](#); [Lu et al., 2007](#)). The urban sprawl or 'pie style' development has become one of the most widely discussed issues in China's urban studies. Rapid economic development greatly improves people's welfare, but also brings serious challenges. As the capital and largest city, Beijing is a leading example of this trending expansion, and its migrant population has been increasing for decades. These changes have caused serious environmental and social problems, especially as they put stress on traffic congestion. The government intends to develop multi-centres to solve these issues. According to its newly published master plan, the 'Beijing City Master Plan (BCMP), 2004-2020', the government intends to restructure Beijing's urban spatial structure to decentralize its services ([Beijing Municipal Planning Committee \(BMPC\), Beijing Institute of City Planning, & Beijing Academy of Urban Planning, 2006](#)) by 2020. However,

questions, such as whether the polycentric structure can be achieved based on present development trends and whether the corresponding policies planned are adequate, remain unanswered.

Polycentric development in metropolitan areas attracts a great deal of academic attention. The urban spatial economy up until the 1970s has generally been considered a conformation of employment concentration in Central Business Districts (CBDs), middle-class residential neighbourhoods and industries in suburbs ([Fernández-Maldonado et al., 2014](#)). Since then, metropolitan areas have stretched out into discontinuous, borderless and decentralized urban forms with a growing number of sub-centres accommodating new economic activities ([Lang, 2003](#); [Garreau, 1991](#)). During urban decentralization, jobs are relocated following the rapidly increasing scale of residential suburbanization, accompanied by all kinds of service sectors ([Muller, 1981](#); [Fernández-Maldonado et al., 2014](#)). Since the early 1980s, ever-expanding suburbanization, together with growing automotive dependency, expanding road systems, and non-spatial trends such as widespread use of information and communications technology (ICT), and the emergence of the global service economy, has led to a post-industrial form of urban agglomeration ([Phelps & Ozawa, 2003](#)), a fundamentally new spatial form and organization of polycentric metropolitan areas.

As an urban economic activity, this relocation trend is explained as the result of the tension between two economic forces, agglomeration economies and diseconomies, which are both dependent on the spatial proximity of economic activities and coexist in large cities, but act in opposition to each other. Agglomeration economies are regarded as cost saving whereas diseconomies increase costs, although both result from the concentration of production at a given location. Firms tend to cluster in urban cores to take advantage of agglomeration economies. When congestion costs tend to exceed these advantages, firms move outward to suburban areas. The scaling up of polycentric structures is explained by increasing geographical scales of agglomeration economies ([Parr, 2002a, 2002b](#)) or of specific industries due to changes in technologies of production, transport and communication ([Phelps & Ozawa, 2003](#)).

Most of the research on urban polycentricity has been focusing on cities or regions in developed countries, with little attention paid to rapidly growing cities in developing countries such as China ([Yue, Liu, & Fan, 2010](#)). Although research has recently begun to emerge in China, it predominately concentrates on urban geographic land-use patterns ([Long et al., 2013](#); [Wang, H. et al., 2013](#); [Yue, Liu, & Fan, 2010](#)), analysing polycentric urban development based on the direction of urban expansion, urban-rural gradients, growth type and physical urban land-use dynamics. [Long et al. \(2013\)](#) forecast the distribution of future sub-centres in Beijing based on present land-use trends. [Qin and Han \(2013\)](#) study the relationship between real estate prices and location characteristics in Beijing and concludes that there are new sub-centres emerging, such as Zhongguancun and Olympic Park.. Rarely is there research focusing on how these centres function rather than on their geomorphological aspects, despite the likelihood that in studies of urban polycentricity, economic and other functional aspects are likely to carry more meaning. Furthermore, the existing studies usually focus on demonstrating the mechanisms, characterizations and dynamics of the formation of polycentric urban structures, or apply methods to identify the polycentricity of a metropolitan area, which both draw heavily on historical data to form conclusions. Questions faced by China's policy makers, such as 'Could polycentric spatial structures be formed under present land-use or transport

policies?’ have not been well answered. China's economic boom has empowered growth-oriented local governments, and urban land-use has become a major concern for local officials aiming at economic growth and reductions in rent-seeking ([Ding & Lichtenberg, 2011](#); [Wei, 2012](#)). In China, urban development and specialization are neither accidental nor purely market-driven, but rather they emerge as a consequence of state priorities ([Liao & Wei, 2014](#)). The government decides the pattern of physical land-use to a large extent, overseeing the urban activity distribution. Thus, it is more practical to model the evolution of the functional polycentric structure of a city based on land-use policy scenarios instead of the rigid physical land-use pattern change.

In order to identify the extent of polycentric urban structure formation by 2020, under a continuation of current land-use policies, this research develops a Beijing Land-Use/Transport Interaction model (LUTI) to simulate the urban spatial evolution and predict activity distributions (e.g. household and employment locations). The paper is organized into five sections, including this introduction. Section 2 reviews the approaches used in sub-centre identification. Section 3 presents a detailed description of the Beijing LUTI (BJLUTI) model, followed by a Beijing case study in Section 4. The paper ends with discussion and conclusions in Section 5.

2. SUB-CENTER IDENTIFICATION

Polycentricity was conceptualized in the early 20th century ([Burgess, 1925](#); [Harris & Ullman, 1945](#)). It has been interpreted using various criteria at different spatial scales ([Yue, Liu, & Fan, 2010](#); [Waterhout, Zonneveld, & Meijers, 2005](#)). Although traditionally it referred to intra-urban agglomeration (the outward diffusion from big cities to smaller cities within their urban fields or spheres of influence), recently it has been used at interurban or interregional scales to denote polycentric urban regions ([Kloosterman & Musterd, 2001](#)) or mega-city regions ([Scott, 2002](#)).

Sub-centres are defined as locations with larger job concentration and density than their surrounding areas. A sub-centre, should be large enough to significantly influence the functioning of cities, especially their transportation systems, land value and population distribution ([McMillen, 2003](#)). For example, [Giuliano and Small \(1991\)](#) define an employment centre as having a minimum 10,000 jobs and 5000 jobs per square mile. Currently there are no standard methods or measures to identify sub-centres. [García and Muñiz \(2005\)](#) distinguish five different approaches to identify sub-centres as shown in Table 1: the thresholds approach uses job concentration and density ([Giuliano & Small, 1991](#)); the density peaks approach uses the peaks of job density, or the ratio of jobs to the resident population; the mobility approach focuses on mobility flows; and the residues approach is a relative method developed based on the size of deviations from the density of employment functions of the city. Some studies use econometric regressions, which may be better suited to comparing regional urban systems than applied to metropolitan areas.

Table 1. Approaches for identification of sub-centres

Approaches	Criteria
Thresholds	Density of jobs per hectare. Appropriate cut-off points vary across urban areas.

Mobility	Commuting flows
Density peaks	Peak of job or ratio of jobs to resident population
Residues	Exponential job density, weighted regression, Flexible Fourier with distance to sub-centre, etc.
Spatial econometrics	Total and local Moran index (job density or job/population)

Source: [García and Muñiz \(2005\)](#)

These approaches are all concerned with densities whose thresholds usually vary across urban areas and are inherently difficult to define. In China, the statistical data for cities like Beijing is usually collected at smaller scales (e.g., towns) with more variation – the outer towns often have a much larger area than the inner ones. The average densities of activities may not accurately reflect the distribution of sub-centres; on the other hand, the commuting patterns of cities in China are different from those in developed countries. For instance, residents in Beijing prefer to live in zones with better transport accessibility over better environmental quality if there is a choice between the two. Previous studies in urban location and transport cost modelling ([Von Thünen, 1826](#); [Alonso, 1964](#); [Muth, 1969](#); [Mills & Hamilton, 1972](#)) show that rent (or property price) plays a key role in defining the sub-centre distribution of a metropolitan area. In the following sections, we develop a LUTI model to simulate the urban spatial evolution process, forecast housing rent distribution, and analyse the extent of polycentric urban structure change under the present land-use policies.

3. MODEL DEVELOPMENT

The urban development of a city is the process of spatial evolution of various activities interacting with each other via transport, during which the spatial distribution of activities changes continuously, leading to the changing distribution of demand for floor space and property rent.

The urban Land Use/Transport Interaction model (LUTI) is an effective tool for modelling the described interaction process ([Coppola et al., 2013](#); [Simmonds & Feldman, 2011](#); [Wegener, 2004](#)). It provides an abstract representation of the interaction between two main components of urban areas, transport and land-use ([Torrens, 2000](#)). ‘Land-use’ in the LUTI model does not commonly refer to the physical use of land dominated by buildings and transport, rather the social and economic activities occupying floor space. In a LUTI model the two components are inter-linked: the land-use indicators, such as the population and employment forecast, are used by the transport component to generate demands for transport; the travel time and costs forecast by the transport component, derived from the demand and supply of transport, are used in the land-use model to calculate urban accessibilities, which in turn leads to land-use change. LUTI models have traditionally been used to simulate the possible effects of new policies or projects (especially those related to transport) on existing urban systems ([Zondag et al., 2015](#); [Aljoufie, 2014](#); [Echenique et al., 2012](#); [Wegener, 2004](#); [Foot, 1981](#); [Lowry, 1964](#)). This research is intended to develop an activity-based LUTI model to forecast the change of urban activity and rent patterns and test polycentric development policies. The current research assumes that urban activities, including both residential and business activities, abide by the location utility maximization rule.

3.1 Beijing Land-Use/Transport Interaction Model

The proposed model will be called the Beijing Land-Use/Transport Interaction Model (BJLUTI). As a universal model, it is developed from an urban activity perspective with two categories of activities, household activities and non-household (or employment) activities, which generally provide jobs for households. The BJLUTI model simulates and projects variations of property rent, and subsequently identifies future sub-centres based on the present policies.

The model, as shown in Figure 1, comprises two main components, a land-use model and transport model. While the transport model estimates accessibility by zone, based on generalized transport cost and the spatial distribution of urban activities, the land-use model estimates the distribution of activities based on zonal accessibility and floor space distribution and utility of consumption.

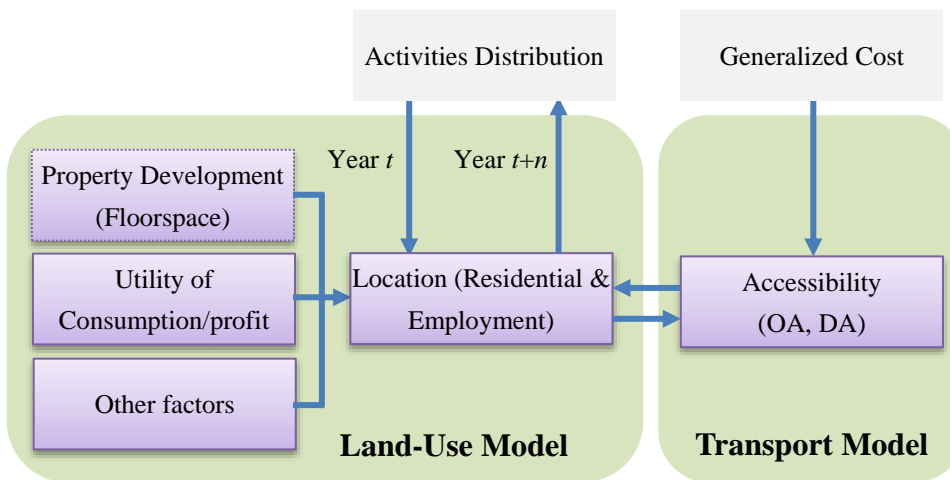


Figure 1. BJLUTI model

The BJLUTI model consists of five sub-models as shown in Figure 1: Property or Floor space Development model, Utility of Consumption model, Location model (Residential and Employment) and Transport Accessibility model. Activity distribution and generalized cost are two exogenous variables used by the Land-Use model and Transport model respectively. The model is solved by an equilibrium solution as illustrated in the following section, where any changes that occur in the territorial system will subsequently lead to a new equilibrium state. As this study is intended to test land-use policies, the Property Development model is not implemented and the property development index is taken exogenously.

3.2 Transport Model and Zonal Accessibility

Zonal accessibility is an indicator measuring one's ease of access to the collective opportunities, such as all jobs available from the zone, and how well the transport system can help one to reach these opportunities.

Two primary factors affect zonal accessibility, which are the transport costs between zones and the opportunity distribution within zones. The number of opportunities in a zone gives weight to the expression of the zone in equation (1) (Niu & Li, 2017). The definition of opportunity depends on the purpose of a trip. For instance, the number of jobs in one zone is used as the weight of that zone to calculate the accessibility of other zones in terms of home-work commuting. The

transport cost between zones is estimated by time cost, determined by the distance between zones, and the road types in the model. A connection between two zones may involve a few segments of different road types, such as national, provincial and county roads. In contrast to the traditional methods used to calculate the transport accessibility (Wang, Y., Monzon, & Di Ciommo, 2015; Zondag et al., 2015), this model develops a logsum formula associated with a logit model of destination/origin choice as follows,

$$A_i = \frac{1}{-\lambda} \left(\ln \left\{ \sum_j W_j \exp(-\lambda g_{ij}) \right\} \right) \quad (1)$$

where,

- A_i is the accessibility of zone i ;
- j refers to a zone connecting with i in the area of study;
- g_{ij} is the generalised cost of transport from zone i to zone j ; and
- W_j represents the importance of the connection for A_i .

3.3 Location Cost: Utility of Consumption

We define the utility of consumption as the per household level of satisfaction obtained from their income and expenditure on two goods, namely housing space, and other goods and services (*ogs*), and this is calculated based on the Cobb-Douglas function (Cobb & Douglas, 1928),

$$U_{pi} = (a_{pi}^H)^{\beta_p^H} \cdot (a_{pi}^O)^{\beta_p^O} \quad (2)$$

where,

- U_{pi} is the utility that households consume during period p in zone i ;
- a_{pi}^H is the average housing space per household;
- a_{pi}^O is the average expenditure spent on *ogs*; and
- β_p^H and β_p^O are the propensities to spend the income available on housing space and *ogs* respectively.

Households are assumed to prioritise their expenditure on housing space and *ogs* to maximize their utility of consumption. Here, the sum of the two variables (β_p^H, β_p^O) equals 1.

3.4 Location Model

3.4.1 Residential and Employment Location Model

The Location model includes two components, the Residential Location model and Employment Location model. The residential location model forecasts the number of residents by zone in future years. It is developed based on the hypothesis derived from the random utility theory that individuals choose the locations that maximize their overall utility (V). As the processes whereby individuals evaluate locations is an unknown variable, a probabilistic discrete choice model is postulated in which households evaluate zones as a function of factors such as transport accessibility and location attributes relative to their places of work, and the error terms are assumed to be independently and normally distributed. The model assumes that it is the changes of the factors such as transport accessibility and rent that cause the

variation (e.g. household location or relocation) of urban activities. These changes can be weighted and summarized as the location utility change, i.e.,

$$\Delta V_{t+1,i}^H = \theta_p^U (U_{t+1,i}^H - U_{ii}^H) + \theta_p^A (A_{t+1,i}^H - A_{ii}^H) \quad (3)$$

where,

$\Delta V_{t+1,i}$ is the location utility change in zone i during period $t+1$;

θ is the coefficient of change; while

U , and A are the utility of household consumption; and zonal accessibility, from the perspective of households respectively, is used to calculate the changes between periods t and $t+1$.

For utility of employment, variable U in equation (4) would be replaced by cost which is calculated by multiplying the average rent per unit of space using the average space area occupied per unit of employment (i.e. one enterprise).

The number of residents that choose zone i as their place of residence based on their work zones is given by the following distance-deterred formulation,

$$H(L)_{t+1,i} = H(M)_{t+1} \cdot \frac{H_{ii} \cdot \exp(\Delta V_{t+1,i}^H)}{\sum_i H_{ii} \cdot \exp(\Delta V_{t+1,i}^H)} \quad (4)$$

where,

$H(L)_{t+1,i}$ is the increased number of households located in zone i during the time $t+1$;

$H(M)_{t+1}$ is the total increased number of households in the modelled area;

H_{ii} is the total households in zone i at time t ; and

$\Delta V_{t+1,i}$ is the utility change of the households.

The equation is consistent with the economic theory that any increase in employment of an urban system will have multiplying effects on its population.

The Employment Location model, as a reflection of economic activities in the area, is used to determine the zonal distribution of employment. By replacing the terms of households in equation (6) with those of employment, the residential location model can be transformed into the employment location model, i.e.,

$$E(L)_{t+1,i} = E(M)_{t+1} \cdot \frac{E_{ii} \cdot \exp(\Delta V_{t+1,i}^E)}{\sum_i E_{ii} \cdot \exp(\Delta V_{t+1,i}^E)} \quad (5)$$

where,

$E(L)_{t+1,i}$ is the increased amount of employment located at zone i ;

$E(M)_{t+1}$ is the total increased amount of employment to be located in the modelled area;

E_{ii} is the total employment in zone i at time t ; and

$\Delta V_{t+1,i}$ is the utility change of the employment.

3.4.2 Zonal Rent Estimation

The new activity distributions, or densities, estimated by the Location model, lead to the change of rent distribution in the area – the main factor determining the activity utilities, which is in turn used to calculate the activity distributions of the next period. The model estimates the new average rent by

zone as a function of the property supply and demand, and previous rent, constrained by the minimum rent across zones, i.e.,

$$r'_{t+1,i} = \max\left\{r(\min)_t^H, r_{t,i}^H \cdot \left[\frac{\sum a_{t+1,i}^H \cdot H(L)_{t+1,i}}{F(A)_{t+1,i}^H} \right] \right\} \quad (6)$$

where,

$r'_{t+1,i}^H$ is the new average housing floor space rent of zone i, estimated at time t+1;

$r_{t,i}^H$ is the previous rent;

the coefficient α is averaged housing space occupied by one household;

F(A) is the floor space available; and

H(L)_{t+1,i} is the increased number of households.

The employment floor space adjustment can be deduced in the same way.

3.4.3 Flow Diagram of the Location Model

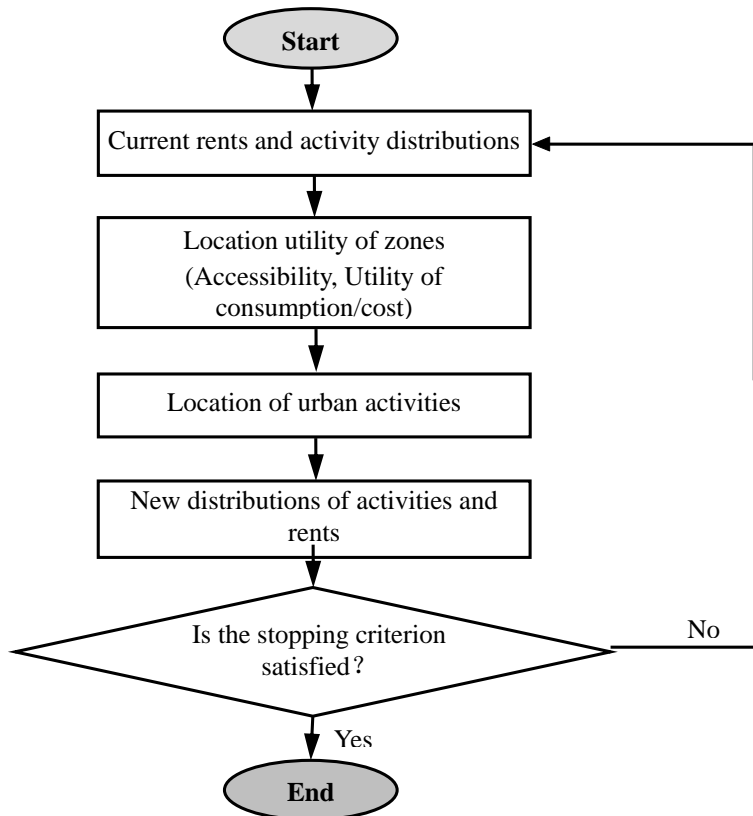


Figure 2. Flow diagram of Location model

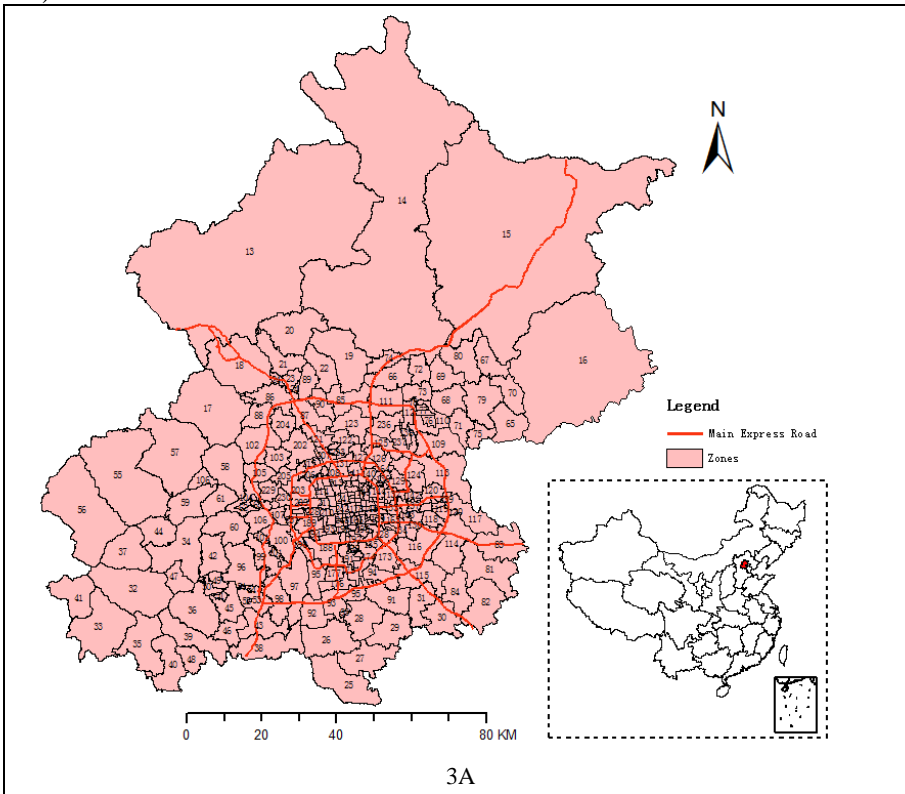
Figure 2 shows the calculation of the Location model where it first calculates the utility and activity changes by zone, based on the changes of transport accessibility and utility of consumption. Then it calculates the location of activities for new activity distributions and tests if the stopping criterion is satisfied. The model stops if the activity distribution changes between two iterations are below the predefined thresholds. Figure 2 is applied to both activities, housing and employment.

4. BEIJING CASE STUDY

4.1 Beijing Metropolitan Area

The BJLUTI model is subsequently applied to the Beijing Metropolitan Area (BMA) with an area of more than 16,410 km², as shown Figure 3A. As the capital of China, the BMA has experienced rapid urbanization with population growth and urban land expansion since the 1978 Country Reform and Opening-Up government policies. Its urban area is around 2,400 km² (495 km² in 1978) with a residential population of 14.91 million, as of 2010 (8.71 million in 1978). Its urban growth trend is expected to continue.

The recent Beijing City Master Plan (BCMP 2004-2020) proposes an urban spatial structure of ‘two axes, two belts and polycentricity’ as shown in Figure 3B. The model is applied here to test whether the current urban land-use policies are adequate to meet the polycentricity target made by the plan. There are eighteen districts in Beijing in total, among which there are four remote mountainous suburban districts, Huairou, Miyun, Pinggu, and Yanqing. We study the central urban area at the scale of townships (or so-called *jiedao*), and the remote districts at the district level. This way, 243 zones are obtained (Figure 3A).



3A

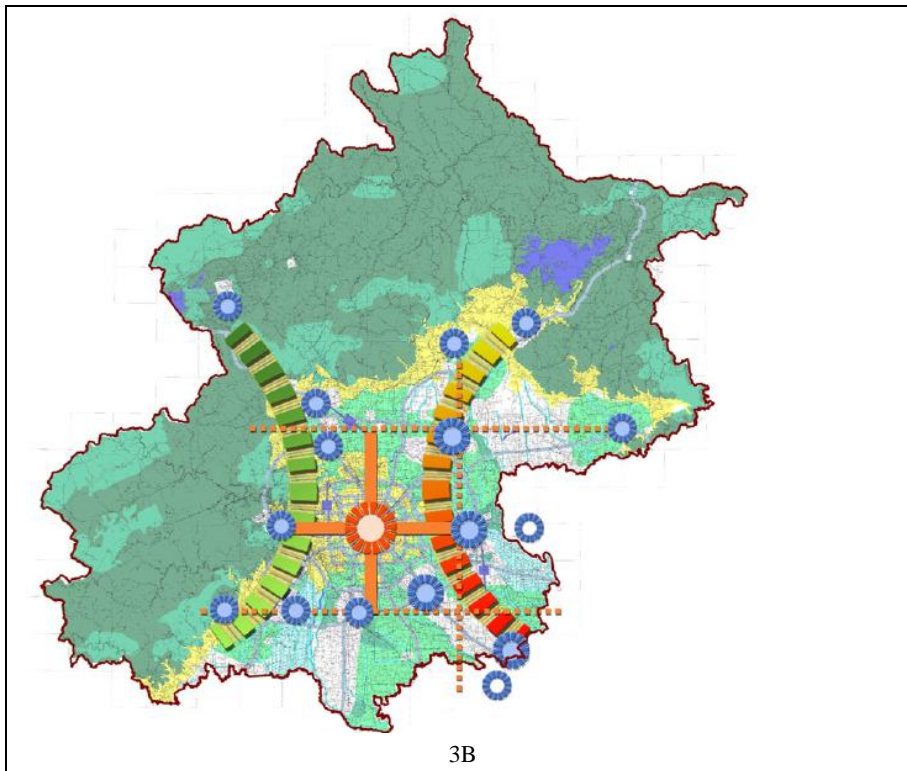


Figure 3. The Planned Spatial Structure of BCMP (Source: BCMP)

4.2 Study Data

The study data comprises two parts: (1) the GIS database of traffic lines and administrative divisions obtained from the Thematic Database for the Human-earth System of the Chinese Academy of Sciences and the 1:4M database from the National Fundamental Geographic Information System of China; and (2) the socio-economic data including demographic data, average household income, floor space, and rent distributions and business distributions, sourced from the China City Statistical Yearbook (2011), China's Regional Economic Statistical Yearbook (2011), China Population and Employment Statistical Yearbook (2011), China's Sixth Census Data (2010), *Sofang* Real Estate Agent ([Sofang, 2014](#)), and the Beijing Businesses Information Survey (2011) data.

The floor space and rent data is collected from *Sofang* Real Estate Agent ([Sofang, 2014](#)), one of the most authoritative websites in publishing periodic property sale and rent prices in China. The 2010 census data used is the latest and most detailed demographic data available, including the full spatial distribution of households by generations. The Beijing Businesses Information Survey has more than 700,000 records, covering all the work units from companies and institutes to schools with respect to their locations, worker numbers and scales.

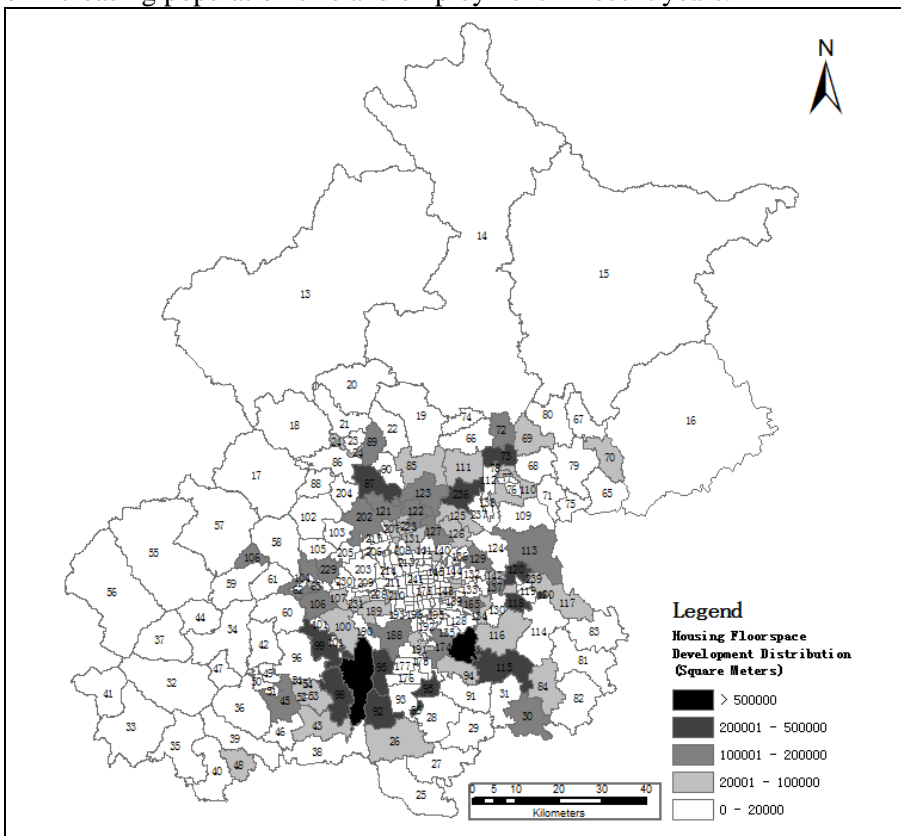
The average income is used for the household income in the model. Time cost is determined here by the distance between zones and the road type. Based on the transport network in the area, the shortest trip between each two zones is calculated and a 243*243 time cost matrix is generated. The property rent for each zone is actually determined by both the demand and supply of market and non-market factors. In order to remove the effects of non-market factors, the rent data is pre-processed to smooth the extremely high and low rent cases. In practice, the model allows the rent to vary between 0.5 and 2 times the average income. Doing it this way would allow for the majority of citizens to

afford the prices; in other words, the property rent in a zone would not exceed the purchasing power of the citizen in that zone.

4.3 Policy Scenario

As Beijing’s subway development plan currently has not been completed and there will be limited change to transport within the foreseeable future (reasonably, within five years), the modelling here concentrates on the spatial structure simulation based on the current land-use trend given an unchanged transport network.

Based on the activity categories previously defined, Beijing land-use, valued by floor space is classified into housing floor space and employment floor space. The government sells land to developers on a yearly basis with restrictions on type of floor space and the permissible degree to which each piece of land can be developed. These land sales reflect the spatial policies of the government. The model takes the average permissible floor space development from the land trade data between 2009 and 2013 as the floor space development trend. Figure 4 shows the average spatial distributions of housing and employment floor space development. The household and employment growth rates are set to 0.023 and 0.20 respectively, based on the average rates of increasing population size and employment in recent years.



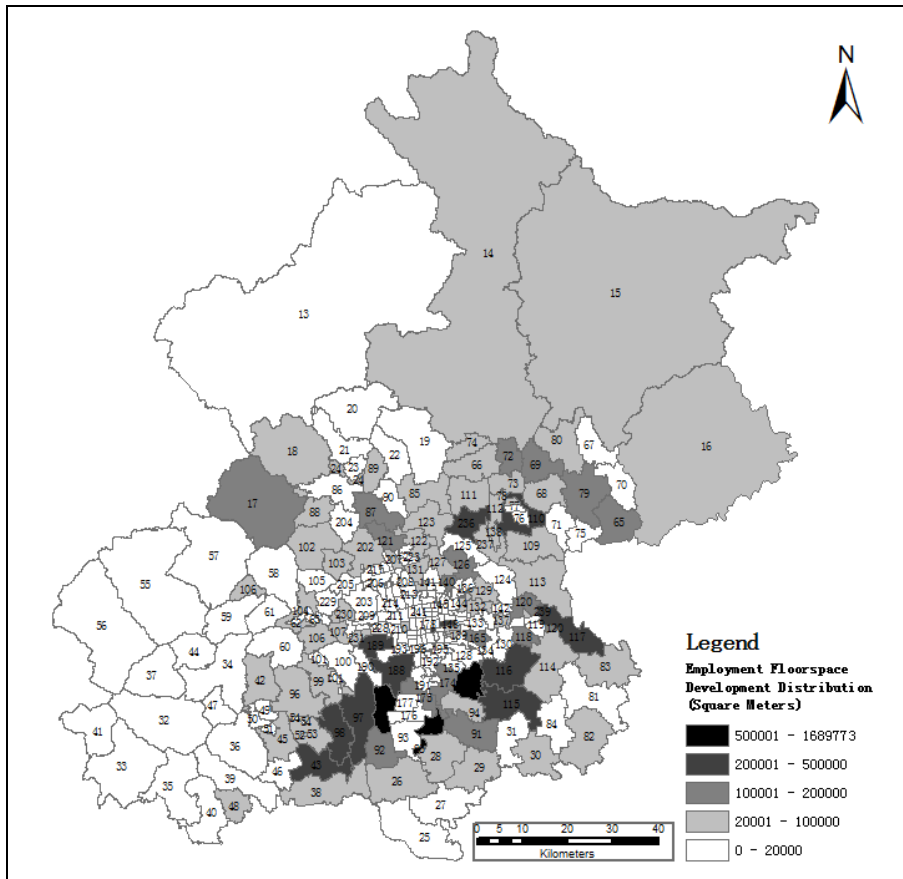


Figure 4. Development of housing and employment floor space

4.4 Rent Distribution in 2020 and the Growth Pattern

The rent distribution forecast for 2020 is shown in Figure 5. The majority of zones with higher rents are still located in the city. Although some suburban towns adjacent to the 6th Ring Road, such as the *Shisanling* (21), *Chengbei* (23) and *Chengnan* (24) clusters, and *Fatou* (25), *Datai* (59), *Beishicao* (74), *Xiji* (83), *Junzhuang* (105), *Airport* (138) and *Qingyuan* (177) have slightly higher rents than their surrounding areas, their spatial distribution patterns show no distinct sign of change from the current statistic. Figure 6 also demonstrates that of the four remote counties, *Yanqing* (No. 13), *Huairou* (No. 14), *Miyun* (No. 15) and *Pinggu* (No. 16), *Pinggu* has higher rent, largely because it is closer to the centre of the city.

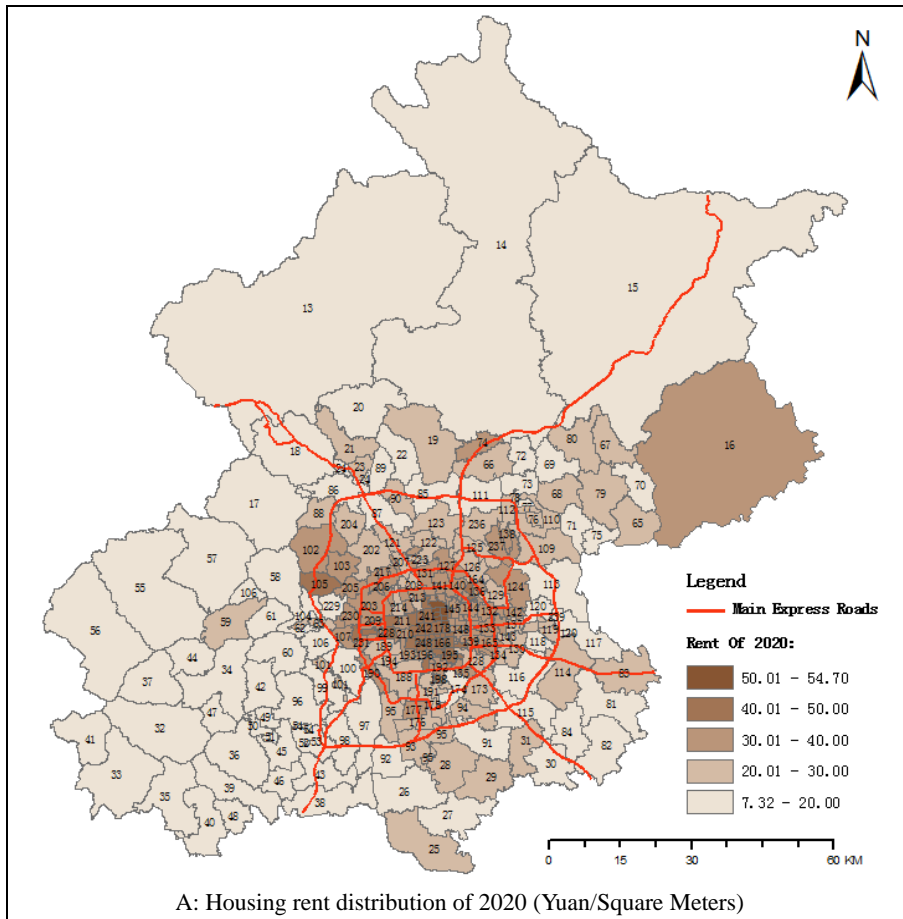


Figure 5. Housing rent distribution for 2020

The rent change of a zone indicates the zone's potential to become a sub-centre, given the continuation of current development into the future. To check the difference of rent change across zones, the forecast rents in 2020 with the rents in 2010 are compared in Figure 6. It shows that housing rents in some zones decrease, partly due to government policy incentives towards the city's suburban areas. According to the household location utility maximization assumption of the model, the households will likely move to zones with lower rents, causing the decrease of their original zones' rents. This implies that developing more suburban floor space may decentralize the oversaturated activities in the city. By comparing the housing rent change pattern in Figure 6 with the housing development pattern in Figure 4, we can see that the pattern of zones with increasing rent clearly differs from the pattern of housing development. This is expected, as the rents of zones with more housing developments tend to decrease more as other variables remain unchanged. In Figure 6, there are some zones shown with black and white dots whose rents increase more significantly than the surrounding zones, which could potentially be developed into sub-centres. The BJLUTI model assumes that the transport accessibility change determines the location preference of the households, while employment rises as employment floor space is developed and subsequently the transport accessibility is improved. To develop more sub-centres, sophisticated policies towards employment increases should be enhanced.

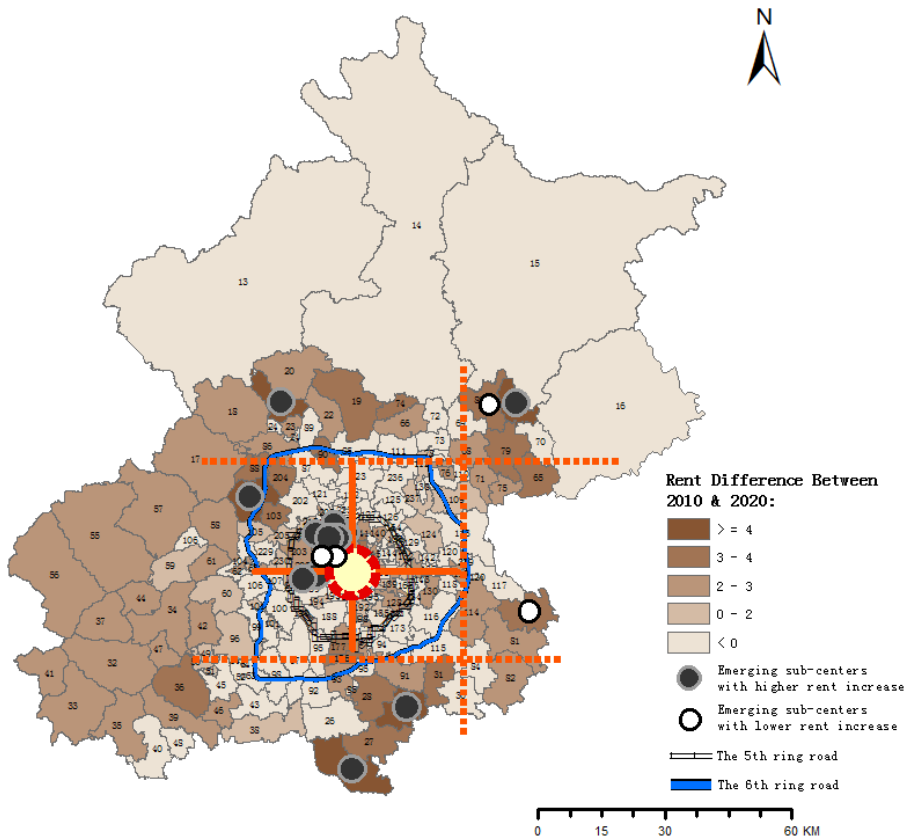


Figure 6. Housing rent change pattern between 2010 and 2020 (Yuan/Square Meters)

As the BCMP plans to develop sixteen more sub-centres by 2020 (see Figure 3), sixteen zones are grouped into two categories based on the scale of rent increases as shown in Figure 6. Zones in the first category with the highest rent increases are marked by black dots, and others are marked by white dots. Among these sixteen potential sub-centres, nine of them are inside the 5th Ring Road of the city, while the others are in the outskirts, outside the 6th Ring Road, which has a similar spatial pattern to the employment floor space development distribution shown in Figure 5. This is justified as more employment floor space will lead to more employment and ultimately increase the housing rent.

To check the extent of the planned polycentric spatial structure formation, the forecast result in Figure 6 is compared with the one planned by the BCMP in Figure 3. It shows most of the potential sub-centres forecasted are located in the outskirts, which is consistent with the plan. However, the exact locations or spatial patterns differ. Only seven potential zones outside the 6th Ring Road are a reasonable distance from the centre of the city to form a polycentric structure. Nine potential zones inside the 5th Ring Road are too close to the city centre to form polycentric-cities. As both the transport system and land use system could affect the spatial structure, in order to achieve the planned goal of sixteen sub-centres, the current policies need to be revised to develop more employment floor space and public transportation in the target locations.

The modelling results demonstrate that, given the present land-use development trend, the polycentric structure will not be formed by 2020 and the zones with the potential to become sub-centres form a very different spatial pattern from the plan. In order to reach these objectives, land-use policies need to be adjusted, accompanied by enhanced transport policies. More employment floor space development and improved transport will be critical for achieving the 2020 goal.

5. DISCUSSION AND CONCLUSIONS

Due to the lack of census data for the forecasted years, rents are used and validated against the observed data of 2014 (Sofang, 2014). The results between the two show an encouraging correlation, $R^2=0.74$. Appropriate data pre-processing (stated above) also plays an important role in achieving this .fit. The model states that the rent positively correlates with the income level of households. In the model, the observed rents are calculated as the household expenditure on the unit of floor space based on the household's income level, adjusted by a ratio factor, (the total household expenditure by floor space over the total floor space value), such that rents that are extremely high or low are dropped before the modelling process starts.

The nature of the present analysis has been primarily exploratory with regard to the methodology. This study develops an integrated land-use/transport interaction model to forecast housing rent distribution based on floor space development. The model is then applied to the case study of Beijing to forecast the rent distribution for 2020 and measure whether the present land-use policies can achieve the polycentric planning objective. The results show that: 1) by 2020, the polycentric spatial structure planned by BCMP will not be achieved; 2) some zones have the potential to be sub-centres based on the present land-use policies; 3) however, these zones form a different spatial distribution from those sub-centres planned by the BMCP. The results provided have implications for the government regarding how it may intervene in urban spatial development in order to achieve its goal of forming a polycentric city in the Beijing metropolitan area.

The model does not introduce any transport policies as transport systems usually change more slowly, although it is definitely within the capacity of the model to examine transport policies. The transport accessibility and generalized cost variables ensure that the BJLUTI model provides strong functionality for transport policy simulation. Meanwhile, the generalized transport cost variable provides an interface for other transport tools such as START, TRAM and TRIPS. Integration with these tools may potentially enhance the BJLUTI model's capacity to evaluate the impact of new transport interventions.

The proposed model is useful in examining current polycentric policies and forecasting urban spatial development, and could be a baseline for modellers in this area in China. The model can also be used to simulate urban growth or other policy scenarios based on various urban strategies, through which the best scenario or policies can be identified. The next version of the model is already under development, and will include more variables, such as traffic, household categories, and green land ratio and population density. To the best of our knowledge, there are few successful precedents in China using the LUTI model of development and application. This research forms a good basis for applying quantitative LUTI models to urban planning studies in China.

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