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Understanding Beijing's Moving Urban Fringe through a Spatial Equilibrium Model

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Abstract: The growth of the main built-up area of Beijing is characterised by a pancake like expansion, from 100 km^2 in 1950 to 1210 km^2 in 2005 in successive waves. The approach to future urban expansion will require careful consideration, as economic, environmental and social conflicts at the urban fringe have intensified. Two successive greenbelts have been designated to contain expansion and engender more compact growth. However, the first greenbelt has not been achieved successfully and many areas designated as the second greenbelt is facing implementation challenges. This paper builds on existing research into greenbelt policy implementation and investigates the impacts of alternative urban growth boundary proposals under a systematic modelling framework. It reviews the theoretical insights into growth at the urban fringe, and puts forward a methodology that links development at the urban fringe to the functioning of the entire metropolitan area. It outlines six alternative development scenarios that encompass the existing planning proposals for the urban fringe: trend growth, densification, stringent greenbelt, loose greenbelt, hybrid controls, and green wedges. We use a prototypical spatial equilibrium model to quantify the performance of the development scenarios in terms of production costs, consumer welfare, wages, floorspace rents, and commuting times. The analyses suggest that the physical forms of fringe area development do significantly affect the economic performance of the whole municipality. Alternative proposals, including those that have rarely considered in the past, should be investigated carefully in this light, in conjunction with related studies on social and environmental impacts of urban fringe development.

1. INTRODUCTION

1.1 Background and motivations of the paper

Urban form policies can have important impacts on local environmental quality, economy, and social equity (Echenique et al., 2012). A fringe of a city is a transitional zone where urban land use and rural land use mix and clash. Typically, this is the area where the bulk of new construction takes place, and it therefore plays a crucial role in shaping the city. There have been many attempts to control the development of the urban fringe for a variety of policy objectives. There is a wide variety of planning strategies.

For example, in the UK greenbelt policies have existed for more than 60 years to control the ribbon development and sprawl of London and many other cities (Hall, 1973); urban growth boundary policies have a long tradition in the United States (Staley, 1999; Jun, 2004).

This historic perspective of 50-60 years of past implementations is an enormous resource for planners in fast urbanising, emerging economies. It has the potential to make the complex planning tasks somewhat easier in the fast growing cities today. However, planners in the emerging economies are often discouraged by the fact that policies from the developed country cities such as the greenbelt policy do not seem to lead to the same historic outcomes (e.g. planned greenbelts do not seem to work). Furthermore, even if the policies have achieved the same outcomes today (e.g. the greenbelt policy has contained urban growth), how could we be confident that the same outcome in an entirely different era and socio-economic context is beneficial to the city?

In this regard, Beijing is a typical example of cities encountering such challenges. In the past 60 years, with rapid economic growth, the annual population growth rate in Beijing has reached 3.8% and overall population has reached 19.6 million in 2011 (National Bureau of Statistics of China, 2011). The built-up area has been expanding rapidly from 100.2 km^2 in 1950 to 1210.2 km^2 in 2005 (Ai et al., 2008) following a concentric pattern of expansion (Figure 1).

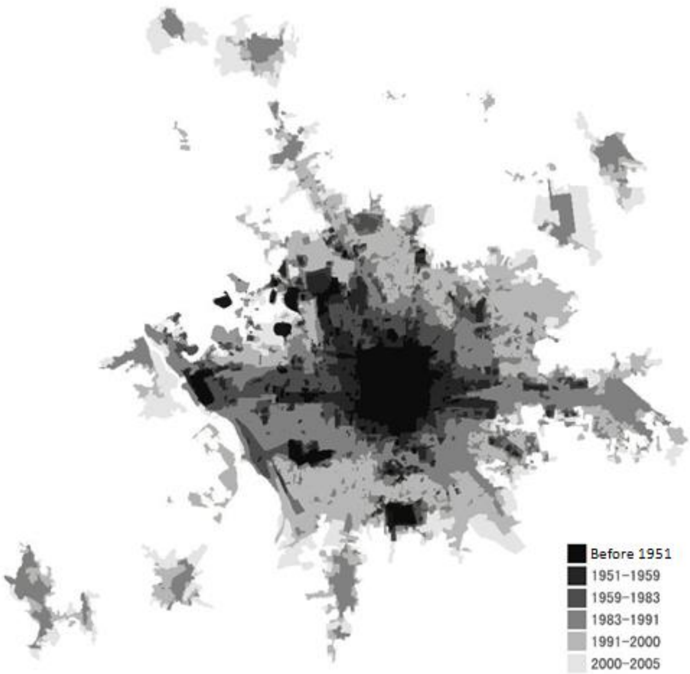

Figure 1. Expansion of built-up area of Beijing 1951-2005 (Source: Wu, 2010)

Although in Beijing Master Plan 2004-2020 it states clearly that Beijing should abandon the mono-centric sprawl pattern and make a transition into a polycentric pattern, this pancake-like expansion has not shown any signs of abating since this policy was launched. In order to tackle the sprawl pattern, two successive greenbelt policies have been put forward (Beijing Municipal Government, 1994, 2003). The First Beijing Greenbelt policy was introduced in 1994. 125 km^2 of green areas around the fourth ring-road of Beijing were designated as the First Beijing Greenbelt. However, the urban expansion in the mid to late 1990s spread across this designated greenbelt land. The total built-up area within the designated First Greenbelt increased from 33.3% in 1993 to 49% in 2005, with a corresponding decrease in the green area from 66.7% to 44.3% (Han and Long, 2010). The Second Beijing Greenbelt was introduced in 2003 with a designation of 1556 km^2 of green areas between the fifth and sixth ring-roads. However, new construction within the designated area appears to continue. The greenbelt as a standard instrument for controlling fringe growth in so many cities in the developed countries, including London, Paris, Ottawa, Ontario, Seoul, Frankfurt, Vienna and so on, seems particularly difficult to achieve in Beijing (Figure 2).

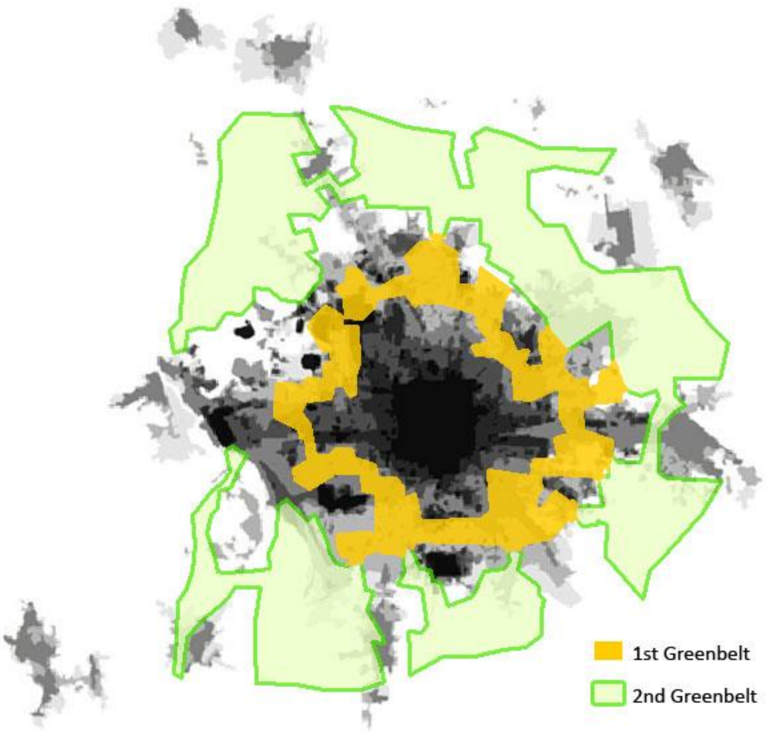

Figure 2. Greenbelt boundaries (drawn by the authors)

It goes without saying that greenbelt designation is not the only planning instrument to control urban growth. The planners in Beijing have explored a wide variety of alternative polices, for example Wu (2010) has identified the Tokyo approach (i.e. densification of the main city) and the Paris approach (i.e. large and intensive suburban new towns) as alternative strategies to the greenbelt proposal.

1.2 Evaluate impacts of urban form policies on the whole municipality

Preferred by many physical planners, Beijing's greenbelt policy is a mainstay of government policy. Current analyses of this policy emphasise the difficulties of putting it into practice: government is facing challenge of providing displaced farmers adequate social welfare (Fu, 2010; Ji, 2011); it is becoming extraordinarily expensive to remove villages and compensate farmers (Fu, 2010); it is extremely hard to control the land use within the greenbelt, for example, there were criticisms that land within the greenbelt was actually used for luxury villas which are developed under the pretext of golf courses (Tan, 2008; Du, 2011); The housing estates to accommodate displaced farmers are far from adequate (Tan, 2008).

However, these criticisms tend to focus on the immediate issues that are hampering the progress of the greenbelt implementation, and there are relatively few studies that relate the role of the greenbelt and the overall impact of urban growth in Beijing. Of course, the impacts of a greenbelt are felt keenly by the residents and workers within the area. Their homes, livelihood, and future work prospects will all change. What is less discussed is the fact that there may be even greater consequences on the growth, prosperity and welfare of the whole municipality. There are several reasons for examining the wider impacts. First, greenbelt limits the land supply of the main city – it acts as an urban growth boundary at a time when the city is facing high pressures of population and business growth, and huge demand for housing. Secondly, for those people who live beyond the greenbelt, commuting time increases if they still work in the city centre. Congestion happens frequently on roads connecting the city centre and the towns beyond the greenbelt.

Additionally, few of the existing critiques analysed economic outputs of a greenbelt in a quantitative assessment, such as land value, wage and production cost and consumer utility. Comparison of welfares with and without greenbelt is descriptive. Amenity value of a greenbelt is investigated in a qualitative way. There has been no mathematical relation established between Beijing's greenbelt policy and indices regarding economic efficiency. Therefore it is necessary to evaluate existing policies comprehensively within a broader context in a quantitative way and this methodology should also be applied to evaluate other urban fringe development policies.

1.3 Modelling urban fringe development policies

Urban models are often used to predict policy performances in urban planning in developed countries. Some of them provide insights into the complex interactions in the development process and help to evaluate long-term effects of policies. In particular, there have been many studies to model the development of the urban fringe.

Some existing researches focused on the impacts of greenbelt on fringe land prices. Lee and Linneman (1998) analysed the amenity effects of greenbelt over time on land market of Seoul and also examined the impact of land prices due to land supply restriction by using an empirical hedonic model. Knaap (1985) measured the effects of Portland greenbelt on land price by introducing a partial equilibrium model. This model describes the effects of a greenbelt on urban and nonurban land values, the demarcation of where zoning changes and future urban development may take place (Knaap, 1985). Both models emphasised amenity value of greenbelt and its impact on land value; however, both static models ignored human behaviour responding to the fringe control policy.

Lee and Fujita (1997) examined the relationships between the types of amenities generated by a greenbelt and the efficient location of a greenbelt by using Herbert-Stevens model (Herbert and Stevens, 1960). By modelling behaviour and purpose of players, the authors calculate the optimal provision of a greenbelt, subject to utility, land supply and population constraint. This mono-centric model was a partial equilibrium model and had not shown economic interactions geographically.

Besides mono-centric partial equilibrium models, researchers developed multi-centric spatial equilibrium models to describe urban moving boundaries, focusing on the relationships between urban economy, activity location and spatial costs.

A general equilibrium model was developed by Anas and Xu in 1999 (Anas and Xu, 1999) to test policy performance on urban form: will congestion tolls lead to a dispersed or centralised pattern? This model analyses consumers and producers' responses of location choice to tolls based on the principle of minimising costs and maximising utility. In an equilibrium condition, wages, prices of products and rent can be computed and compared in different scenarios. Model results show that centralising effects dominate on dispersing effects of tolls. It also implies that congestion tolls can shape compact urban pattern efficiently and affect the whole urban economic system. In 2007 Anas and Liu developed the general equilibrium model into RELU-TRAN model to explain the behaviour of supply, demand and price in a city area with several or many interacting markets (Anas and Liu, 2007).

Based on the general equilibrium model, Anas and Rhee wrote up two articles (Anas and Rhee, 2006; Anas and Rhee, 2007) to compare performance of stringent urban fringe growth control versus congestion tolls. Both articles cast doubts on stringent policies of controlling urban fringe sprawl. Anas and Rhee (2006) juxtaposed congestion tolls and urban boundaries as two alternative policies for eliminating sprawl. They got conclusion that in dispersed city a boundary of any stringency is absolutely harmful. Anas and Rhee (2007) established a dual-centric prototypical model and claimed that if there is cross-commuting between city and suburb, congestion tolls can shrink city size by relocating economic activities while boundaries of any stringency can be inefficient.

As shown in the story, not only land price and players' behaviour, but also activities location and urban economy in response to the fringe land use policies can all be modelled in a quantitative way. Models have involved from partial equilibrium to general equilibrium, so that impacts of a policy on every aspect mentioned above could be tested rigorously.

In this paper, we will use a recursive spatial equilibrium model (RSE Model) (Jin, Echenique, Hargreaves, 2013) to test the performance of urban fringe land use policies of Beijing. This model is being developed in Martin Centre for Architectural and Urban Studies, University of Cambridge and shares some similar characteristics with Anas' model. Moreover, it fills the gap of existing models: it can not only examine impacts of policies on economic indices in individual time period, but also examine dynamics of people and investment in response to economic indices. Data required from this model is more approachable, and most cities already have them, for example, census and input-output table. Details of this model could be found in Jin, Echenique, Hargreaves (2013).

1.4 Aims of the paper

We propose in this paper a generic modelling methodology that helps the economic and physical planners to understand and quantify the main effects of urban fringe development and control policies. The computer model that underlies this methodology can incorporate the socio-economic and infrastructure context of the city when calculating the main costs and benefits of the alternative development strategies. This means that it is possible to assess the planning strategies more precisely in terms of the planned location and intensity of development – not only between the main archetypical alternatives (such as the Tokyo, Paris and London models), but also variants within each main alternatives. The modelling in this paper will be focused on the economic performance of the planning strategies, and it can be extended in future work to cover social and environmental performance. Section 2 proposes a spatial equilibrium model to test spatial options for cities, in order to quantify the impacts of policy levers on urban activities. Section 3 applies the model to the case of Beijing and provides quantitative modelling results. Then model simulation results are compared pair-wise in section 4. In this way, the strengths and weaknesses of each policy option are outlined through quantified evidence. Section 5 presents preliminary conclusions of the research.

2. MODEL DESIGN

In this section, we will propose a generic framework to predict and compare economic performance of large scale urban land use development initiatives, including both the variants of the greenbelt and alternative strategies. We first outline the model structure, and then explain the components of the model.

2.1 Model structure

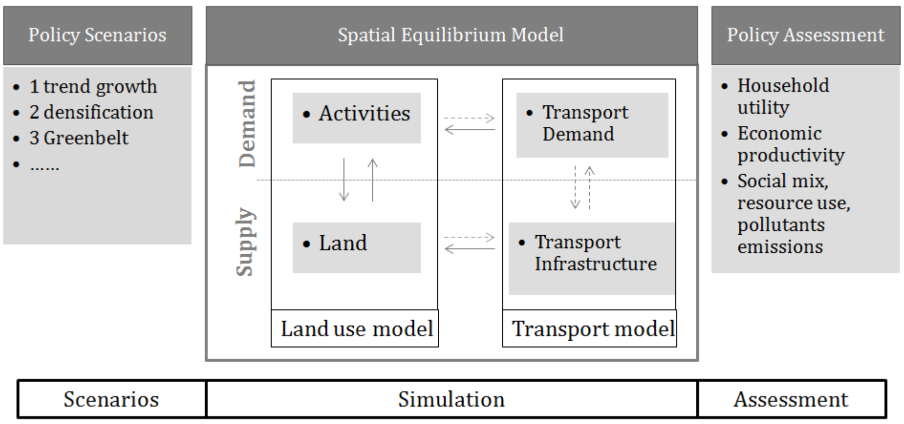

Figure 3. Model structure (drawn by the authors; based on Echenique et al., 2010)

As summarised in Figure 3, firstly, scenarios are identified to explore the policy trend and alternative urban forms. Then the spatial equilibrium model is applied to forecast the likely locational and travel behaviour of households and firms in response to the introduction of policies (Echenique et al., 2010). Finally, modelling outcomes are assessed through economic productivity and household utility.

The spatial equilibrium model focuses on the macro level simulation and explores interactions between urban activities, transport demand, land supply and infrastructure supply. On the demand side, urban activities generate transport demand so that people and goods can move within and between different zones, which also affect urban activities. On the supply side, land supply incorporates with transport and infrastructure supply. There are interactions linking supply side and demand side until an equilibrium reaches. Traditionally, trips generated by land pattern will be substituted into the transport model while transport model will generate updated travel time, cost and distance which will be feedbacks for land use model. In this way, a feedback loop is formed.

However, this paper only focuses on examining the land use side of spatial equilibrium and transport model is used as an exogenous input. Trips generated from land use model will not be used as endogenous inputs for transport model based on a general assumption that the municipality will do its best to maintain the average peak time travel speeds on the transport network so that they don't radically change from base year. The dash arrow lines between the two sub-models in the picture above show this approach.

As mentioned in section 1.3, the Matlab code of the RSE Model (Jin, Echenique, Hargreaves, 2013) will be applied for simulation. However in this paper, we only use the spatial equilibrium part of the RSE Model, examining and comparing equilibrate results from individual time periods. The recursive part of the RSE Model would be left for future test. Therefore, we investigate equilibrium in different time horizons. Model will be calibrated using base year t data and parameters maintain for the year t+30 in order to function the model and predict outputs in 30 years. No inflation is counted over time.

2.2 Spatial Equilibrium Model

2.2.1 Land use model

In order to simplify the model and show preliminary rules, the authors set up several preconditions:

There are two types of players, namely producer and consumer in this model. There are no government and developer, so consumers do not have to pay tax and all rent dividends is shared equally among households. The self-sufficient city consumes everything it produces so imports and exports have not been taken into consideration yet. The city is divided into zones and land use model reveals interaction among zones.

Producers

Producers can choose any zone to locate. The output function of a certain industrial type r in a zone j is:

$$\mathrm{X_{rj}} = E_{rj} K^{\nu} \left(\sum\nolimits_{\forall f} L_{rjf}^{\theta}\right)^{\frac{\delta}{\theta}} \left(\sum\nolimits_{\forall b} B_{rjb}^{\xi_1}\right)^{\frac{\omega}{\xi_1}} \prod\nolimits_{\forall r} \left(\sum\nolimits_{\forall j} Y_{rj}^{\varepsilon}\right)^{\frac{\tau}{\varepsilon}}$$

In this hybrid Cobb-Douglas CES function, primary inputs are capital K, labour force L, industrial floorspace B and intermediate goods Y. E is scale parameter. This function is rendered constant returns by $\nu+\delta+\omega+\tau=1$. Assuming the city produces only one kind of conceptual goods and service by one type of industry, the intermediate goods are not calculated and therefore $\tau=0$ and r=1. The influence of capital is currently not calculated in our model so $\nu=0$. We did not classify labours types therefore f=1. b represents the number of office building types.

Consumers

Consumers can work in any zone, live in any zone and purchase goods in any zone. Each consumer first decides where to be employed. Then he chooses where to reside and do shopping among zones. Assuming there are Q residential housing types. After he decides all the location-related choices, he will choose how many floorspace he would like to rent, how many hours to contribute to work and how many retail goods to buy. For a consumer who lives in a type Q residential building in zone i, works in zone j and shops in zone k, the utility is represented as:

$$\mathrm{U}_{\mathrm{ijk}} = \alpha \ln(\sum\nolimits_{\forall k} Z_{ijk}^{\eta_f})^{\frac{1}{\eta}} + \beta \ln(\sum\nolimits_{\forall Q} q_{rjQ}^{\xi_2})^{\frac{1}{\xi_2}} + \gamma \ln L_{leisure\,ij} + \mu_{ij}$$

Z is the total amount of goods and service a consumer can consume; q is the floor area of his residential place and $L_{leisure}$ is the total leisure time a consumer has in a year, where $1/(1-\eta)$ and $1/(1-\xi_2)$ are respectively the elasticity of substitution between any two retail goods and any two types of housing. μ_{ij} is an idiosyncratic utilities which represents unobserved factors. Since we already set up a precondition that there is only one type of conceptual goods and service, $\eta=1$. $\alpha+\beta+\gamma=1$.

Locational choice

In order to derive the probability of locational choice, a logit model is adopted by specifying the distribution of the idiosyncratic utilities. Assuming μ_{ij} is Gumbel distribution with dispersion parameter λ, the probability P of locational choice can be derived through a discrete choice logit model:

$$\mathrm{P}_{\mathrm{ij}} = \frac{\exp(\lambda U_{ij})}{\sum_{\forall(st)} \exp(\lambda U_{st})}$$

$$\sum\nolimits_{\forall(\mathrm{ij})} \mathrm{P}_{\mathrm{ij}} = 1$$

This probability function can be applied when calculating the probability of consumer's preference of where to buy goods and also where to live and work. It can also compute labour source distribution for producers. The living-working zone pair reveals the spatial distribution of a city.

2.2.2 Transport model

In this paper, as mentioned in section 2.1, transport model is an external component. All the transport information deduced from transport model are used as exogenous inputs for land use model, but outputs regarding transport from land use model will not be feedbacks for transport model yet.

Exogenous transport inputs for land use model include zone to zone travel time, distance and generalised cost. These inputs are utilised when calculating travel disutility, delivered price and deriving utility for consumers and economic mass. Travel disutility T_d is represented as the travel cost plus the value of time in the whole year. Delivered price P_d is mill price plus transport cost.

$T_d = \eta \times T \times (0.01 \times c + w \times t / 60)$

$P_d = 2 \times f_{ratio} \times (0.01 \times c + w \times t / 60) + P_m$

T is the total number of trips per year. c is travel cost, w is wage and t is travel time. P_d stands for delivered price while P_m stands for mill price. η and f_{ratio} are scaling multipliers.

2.2.3 Spatial equilibrium conditions

We assume that all consumers maximise utility and all producers minimise costs. The model is to find an optimised condition that consumers and producers could both maximise benefit, subject to floorspace constraints. A zero profit condition will be set for producers in an open competitive market. The market is zero excess demands, which means zero excess demand in labour market and product market.

Then in labour market, total working hours equals total hours minus commuting and shopping travel time. In product market, total goods and service equals total goods and service consumed by households.

2.3 Assessment of outputs

The model outputs will show the average economic productivity and household utility under different policy trends and these economic indices can also be presented in quantities in zones, including total productions, product price, wages, rents, household utility and economic mass.

The overall consumer surplus in the city region as a household well-being measure may be defined as the change in average household utility divided by the average marginal utility of money (Jin, Echenique, Hargreaves, 2013).

$$\Delta CS = \frac{U_A - U_B}{\frac{1}{2}\left(\frac{1}{\Omega_A} + \frac{1}{\Omega_B}\right)}$$

Where U is household utility and Ω is household time-money budget in base year B and alternative scenarios year A.

3. CASE STUDY

In this section, we apply the Matlab code of the RSE Model incorporating equations above to test alternative policies in the fringe area of Beijing.

3.1 Model parameterisation

There are already established models which gave us references for parameter values. We also conducted tests for some parameters based on statistical data from Beijing. The following table lists the model parameters that have been specified in the equations.

Table 1. Parameters used in the model

Model parameters	Comment	values	Sources
δ	Labour cost share for producers	0.86	Beijing I-O Table, 2000
ω	Business floorspace cost share for producers	0.14	Beijing I-O Table, 2000
ξ_1	Business floorspace variety effects	0.9	Jin, Echenique and Hargreaves, 2013
ξ_2	Housing variety effects	0.9	Jin, Echenique and Hargreaves, 2013
E_{rj}	Residual total factor productivity multiplier	1	Assumed: urban agglomeration effects not considered at this stage of the study
α	Household utility parameter for goods and service	0.36	Beijing Statistic Yearbook, 2001
β	Household utility parameter for housing space	0.14	Beijing Statistic Yearbook, 2001
γ	Household utility parameter for leisure time	0.5	Assumed by the authors
λ	Scale parameter for locational choice	1	Jin, Echenique and Hargreaves, 2013
N	Total number of working days per year	250	Ministry of Labour and Social Security, 2008
H	Hours per day	24	
η	Ratio of travel disutility in the cost of travel	0.5	Own calibration that determines the η according to the observed mean commuting travel distance and times.
f_{ratio}	Ratio of cost of delivering a unit of conceptual goods and service in a commuting trip	0.1	Assumed by the authors

3.2 Prototypical model

A 12-zone prototypical model is adopted in order to simplify policy trends. Urbanised area locates in the centre with a radius of 15 km. A township locates in a distance of 30 km from the urban core, beyond farmland. This prototypical model is divided into 6 zones in each side. Zone 1 is the central city with a radius of 4km. Zone 2 is the inner city while zone 3 is the outer city. Zone 4 is preserved as greenbelt zone with dispersed built-up land. Zone 5 is a satellite town. Zone 6 represents an open-end wider hinterland symbolically. Zone 7-12 represent the same types symmetrically. Pink dots stand for centres of zones, where population concentrates. Dimensions in metre are shown in the picture below.

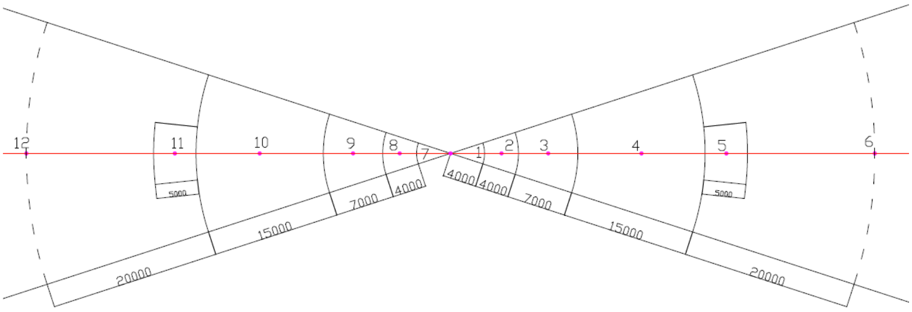

Figure 4. Prototypical model zoning (drawn by the authors)

The prototypical model can then evolve into a model representing situations of Beijing. We classified districts of Beijing into 6 types of city characters according to the prototypical model: the old city centre, inner city, outer city, greenbelt, townships and hinterland. Then data regarding households, floorspace, travel time and distance can be obtained according to this classification.

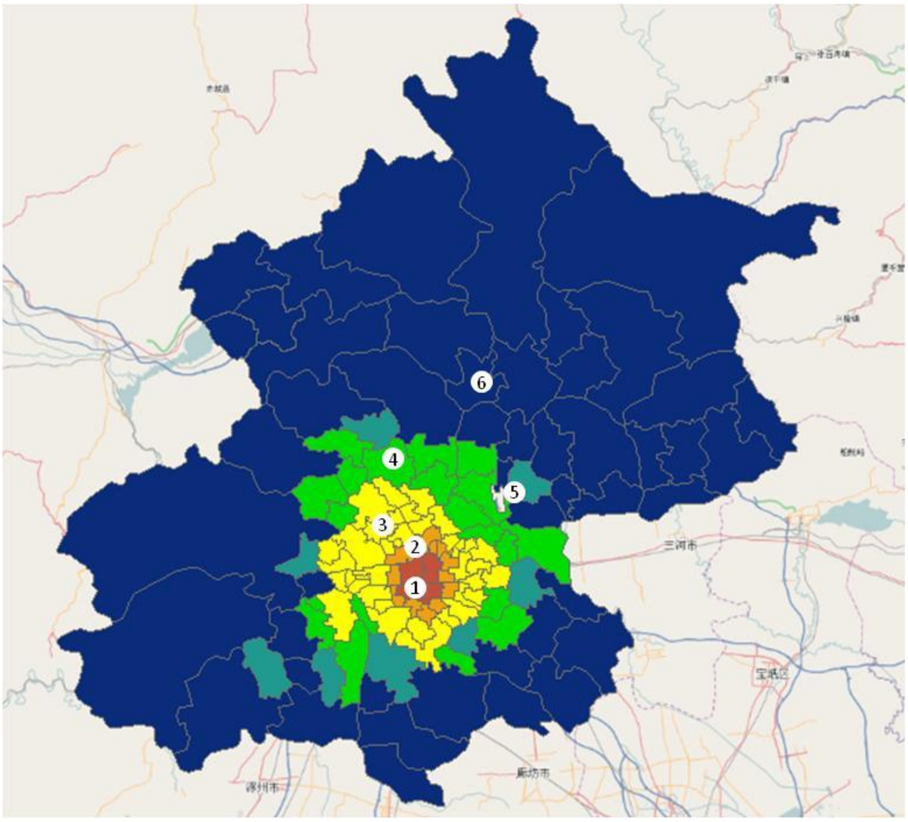

Figure 5. Zone classification of Beijing

We use 2000 as base year to calibrate the model and then run the model for year 2030.

From 2000 to 2010 the total number of population increased by about 1.6 times and we assume from 2010 to 2030, the population number will increase by another 1.5 times. Meanwhile, we assume family size will shrink from 3.1 persons to 2.3 persons per household. Then the total number of household in 2030 will be 3.2 times as many as that in 2000. The total number of household is 4075110 in 2000 and 13000000 in 2030 according to this demographic projection.

In 2000, each household provided 1.7 workers and this number will drop to 1.3 in 2030. We then calculate the total number of jobs and see an increase about 2.5 times through year, from 6900000 to 16900000.

GDP is assumed to increase by 4 times in 2030 compared with 2000, which implies a growth rate of 4.7% per year from 2010 to 2030 (this is compared with the current growth rate of 8%). It follows that the average money income per household in real terms will increase 1.25 times, from 60000 RMB in 2000 to 75000 RMB in 2030[1]. The model operates in real rather than nominal prices, net of inflation.

Table 2. Demographic settings in base year 2000 and predicted year 2030

Year	2000	2030
Total number of household	4075110	13000000
Total number of jobs	6900000	16900000
GDP	G	4G
Workers per household	1.7	1.3
Income per household (RMB)	60000	75000
Persons per household	3.1	2.3

3.3 Scenario design

There are 6 possible policy scenarios for year 2030. The six scenarios have the same demographic settings for year 2030: the same number of household and jobs, and the same family size and income. Differences are represented only in the total amount and the location of housing and business floorspace supply.

1. Trend growth is to continue current trend of expansion, which indicates massive growth in the outer city, townships and hinterland meanwhile natural growth in the centre city, inner city and greenbelt. This scenario assumes that there is no specific planning policy which is put forward to deal with current expansion pattern.

2. Densification scenario is to increase density in the existing built-up area of the main city. This scenario is based on the concept of anti-sprawl compact city.

3. Greenbelt 1 scenario is to implement a stringent greenbelt. New development will concentrate in new towns beyond the greenbelt and greenbelt land is strictly controlled with zero growth. This scenario is developed from current greenbelt policy with the assertion in Beijing's master plan (Beijing Municipal Government, 2004) of new towns development.

4. Greenbelt 2 scenario is to implement a relatively loose greenbelt. Although still assuming zero growth in the designated greenbelt area, development is allowed in not only new towns but also in city and hinterland. This scenario focuses mainly on the greenbelt land control part and leaves the new town development part tested in greenbelt 1 scenario.

[1] Note that this accounts for both the wages and income from investments (represented by property rents in the model). The increase in household income accounts for both the projected increases in wage and rent income per person (from 35000 to 57700), as well as the reduction in household size (from 3.1 persons per household to 2.3 persons per household).

5. Hybrid control scenario is a combination of densification and loose greenbelt. One side of the city follows a compact pattern and the rest implements a loose greenbelt. Because the expansion of Beijing is likely to be uneven in reality, this scenario tests the existence of mixed development strategies and their implementation.

6. The green wedges scenario breaks the continuity of greenbelt into green patches and allows population concentrating around transport nodes in the greenbelt area. Beijing municipal government is striving to construct railway transit and undergrounds and this scenario comes from this TOD concept.

The table below lists the total number of households and floorspace in each scenario. The following pictures 6-12 show the land use intensity in zones. The darker the colour is, the more intensive the land is used.

Table 3. Constraints in scenarios

Year	Scenario	Total floorspace (housing A+ business B)
2000	Base year	A+B
2030	Trend growth	3.2A+2.5B
2030	Densification	2.7A+2.25B
2030	Greenbelt1	3.2A+2.5B
2030	Greenbelt2	3.2A+2.5B
2030	Hybrid control	2.95A+2.375B
2030	Green Wedges	3.2A+2.5B

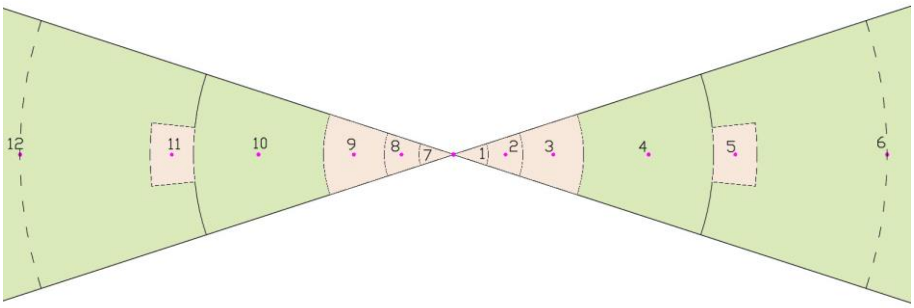

Figure 6. Base year 2000 zonal land use intensity

In the trend growth scenario, the floorspace of central city, inner city and greenbelt, namely zone 1, 2, 4, 7, 8, 10, will increase naturally, for both housing space and business floorspace. Here we define 50% of the total floorspace nature growth. Meanwhile, the floorspace of outer city, townships and hinterland, namely zone 3, 5, 6, 9, 11, 12, will increase more than their natural growth amount, because these areas are currently popular to new development and this trend will continue.

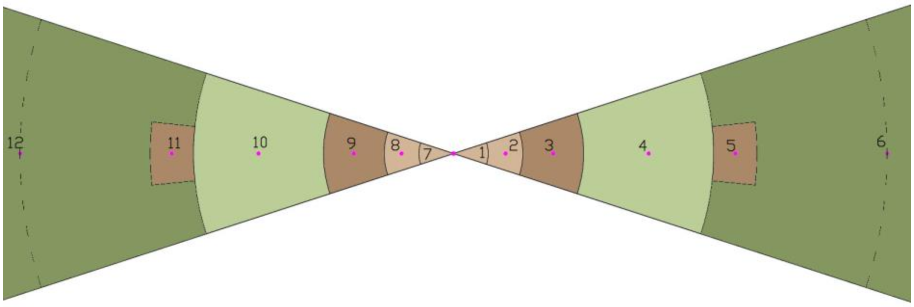

Figure 7. Trend growth 2030 zonal land use intensity

Densification scenario is to confine all new development within main city to control urban sprawl. However, it is not possible to control all the development so we allow 50% of the total built-up floorspace as natural growth in every zone. Then we add the rest constrained growth into zone 1-3 and 7-9 proportionally. Travel time within and between zone 1-3 and 7-9 will then correspondingly increase by 5 to 25 minutes.

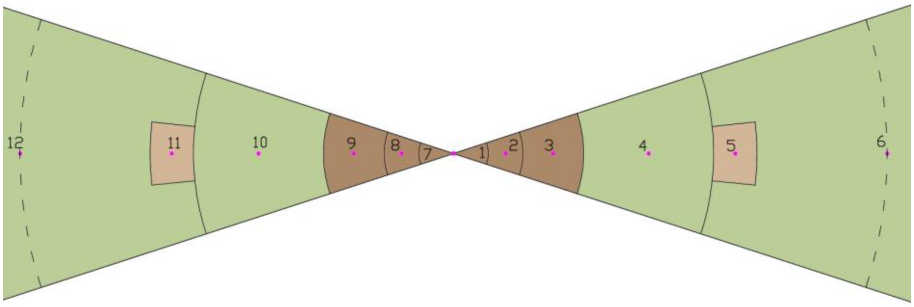

Figure 8. Densification 2030 zonal land use intensity

The Greenbelt 1 scenario is a stringent greenbelt scenario which is to confine the existing boundary of main city and put new development in satellite towns. Similarly, we control the development in zone 1-3, 6, 7-9, 12 and only allow natural growth in these zones. There is zero growth in the greenbelt zones 4 and 10. Then the rest new development will happen in zone 5 and 11. Travel time within satellite towns subsequently increases by 5 minutes. Interzonal travel time increases by 10-20 minutes.

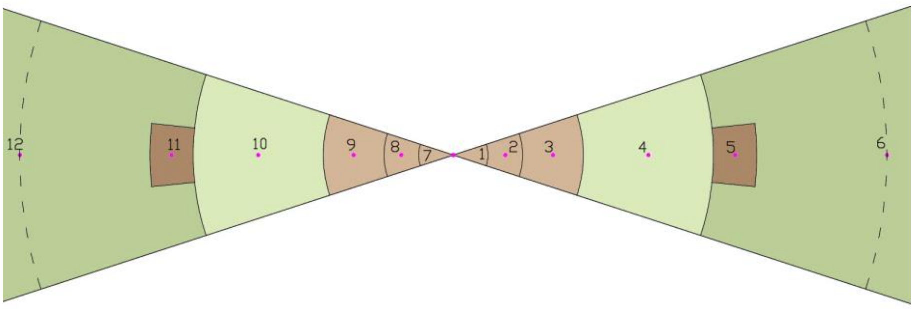

Figure 9. Greenbelt 1 2030 zonal land use intensity

The Greenbelt 2 scenario is a relatively loose greenbelt scenario. In this scenario, growths in zone 1-3, 6, 7-9, 12 are not controlled so the total floorspace increase proportionally. Zone 4 and 10 is still strictly controlled as greenbelt. Zone 5 and 11 not only proportionally increase floorspace but also absorb the developments which are supposed to be in zone 4 and 10. Intrazonal travel time subsequently increases by 5 minutes while interzonal travel time increases by 10-20 minutes.

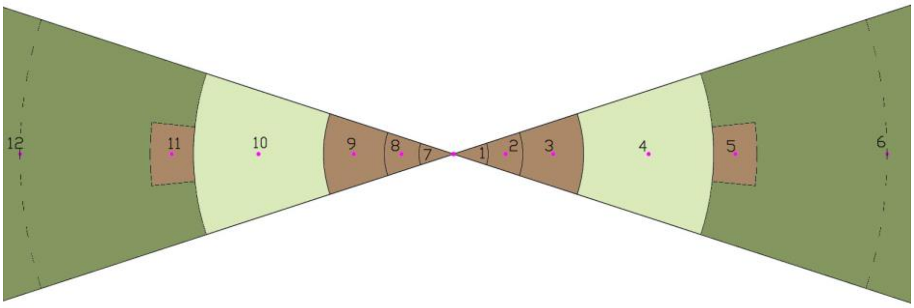

Figure 10. Greenbelt 2 2030 zonal land use intensity

The hybrid control scenario combines densification with the loose greenbelt, as it follows the nature constraint of Beijing: the west of the municipality is a mountainous area and the east is plain. Zone 1-6 is consistent with the pattern of densification scenario. Zone 7-12 is consistent with the pattern of greenbelt 2 scenario.

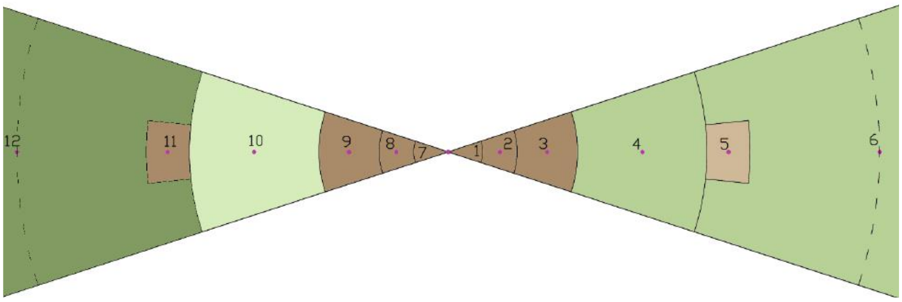

Figure 11. Hybrid control 2030 zonal land use intensity

The green wedges scenario breaks the greenbelt into wedges by allowing new development to happen in the greenbelt zone, around transport node. Nature growth happens in every zone while planned growth happens in not only the satellite towns but the greenbelt zones, namely zone 4, 5, 10 and 11. In zone 4 and 10, new development concentrates around the centroids, which are the transport nodes, and leaves the rest as green wedges. Therefore average travel time decreases in zone 4 and 10 accordingly.

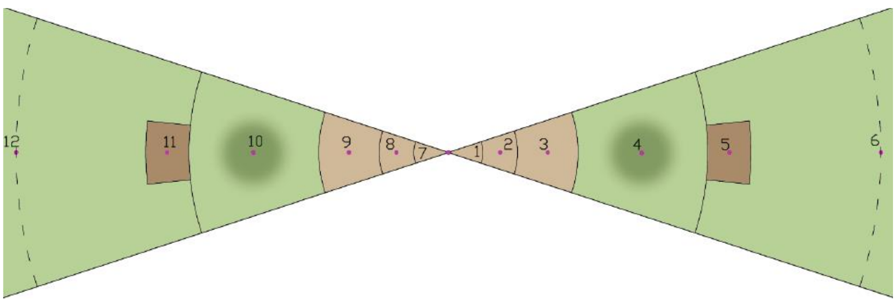

Figure 12. Green wedges 2030 zonal land use intensity

Housing space and business floorspace constraint equations are summarised in the following table.

Table 4. Constraints of zones under base year and 4 scenarios

2000 Base	Housing space	Business floorspace
zone	Total A	Total B
1	A_1	B_1
2	A_2	B_2
3	A_3	B_3
4	A_4	B_4
5	A_5	B_5
6	A_6	B_6
7	A_7	B_7
8	A_8	B_8
9	A_9	B_9
10	A_{10}	B_{10}
11	A_{11}	B_{11}
12	A_{12}	B_{12}
2030 Trend growth	Housing space	Business floorspace
zone	Total 3.2A	Total 2.5B
1	$1.6A_1$	$1.25B_1$
2	$1.6A_2$	$1.25B_2$
3	$1.6A_3+F_3$	$1.25B_3+G_3$
4	$1.6A_4$	$1.25B_4$
5	$1.6A_5+F_5$	$1.25B_5+G_5$
6	$1.6A_6+F_6$	$1.25B_6+G_6$
7	$1.6A_7$	$1.25B_7$
8	$1.6A_8$	$1.25B_8$
9	$1.6A_9+F_9$	$1.25B_9+G_9$
10	$1.6A_{10}$	$1.25B_{10}$
11	$1.6A_{11}+F_{11}$	$1.25B_{11}+G_{11}$
12	$1.6A_{12}+F_{12}$	$1.25B_{12}+G_{12}$
$F_3+F_5+F_6+F_9+F_{11}+F_{12}=1.6A$ $G_3+G_5+G_6+G_9+G_{11}+G_{12}=1.25B$		
2030 Densification	Housing space	Business floorspace
zone	Total 2.7A	Total 2. 25B
1	$1.6A_1+F_1$	$1.25B_1+G_1$
2	$1.6A_2+F_2$	$1.25B_2+G_2$
3	$1.6A_3+F_3$	$1.25B_3+G_3$
4	$1.6A_4$	$1.25B_4$
5	$1.6A_5$	$1.25B_5$
6	$1.6A_6$	$1.25B_6$
7	$1.6A_7+F_7$	$1.25B_7+G_7$
8	$1.6A_8+F_8$	$1.25B_8+G_8$
9	$1.6A_9+F_9$	$1.25B_9+G_9$
10	$1.6A_{10}$	$1.25B_{10}$
11	$1.6A_{11}$	$1.25B_{11}$
12	$1.6A_{12}$	$1.25B_{12}$
$F_1+F_2+F_3+F_7+F_8+F_9=1.1A$ $G_1+G_2+G_3+G_7+G_8+G_9=1B$		
2030 GB 1	Housing space	Business floorspace
zone	Total 3.2A	Total 2.5B
1	$1.6A_1$	$1.25B_1$
2	$1.6A_2$	$1.25B_2$
3	$1.6A_3$	$1.25B_3$
4	A_4	B_4
5	$1.6A_5+0.6\,A_4+F_5$	$1.25B_5+0.25\,B_4+G_5$
6	$1.6A_6$	$1.25B_6$
7	$1.6A_7$	$1.25B_7$
8	$1.6A_8$	$1.25B_8$
9	$1.6A_9$	$1.25B_9$
10	A_{10}	B_{10}
11	$1.6A_{11}+0.6\,A_{10}+F_{11}$	$1.25B_{11}+0.25\,B_{10}+G_{11}$
12	$1.6A_{12}$	$1.25B_{12}$
$F_5+F_{11}=1.6A$ $G_5+G_{11}=1.25B$		

2030 GB 2	Housing space	Business floorspace
zone	Total 3.2A	Total 2.5B
1	$3.2A_1$	$2.5B_1$
2	$3.2A_2$	$2.5B_2$
3	$3.2A_3$	$2.5B_3$
4	A_4	B_4
5	$3.2A_5+2.2\,A_4$	$2.5B_5+1.5\,B_4$
6	$3.2A_6$	$2.5B_6$
7	$3.2A_7$	$2.5B_7$
8	$3.2A_8$	$2.5B_8$
9	$3.2A_9$	$2.5B_9$
10	A_{10}	B_{10}
11	$3.2A_{11}+2.2\,A_{10}$	$2.5B_{11}+1.5\,B_{10}$
12	$3.2A_{12}$	$2.5B_{12}$
2030 Hybrid control	Housing space	Business floorspace
Zone	Total 2.95A	Total 2.375B
1	$1.6A_1+F_1$	$1.25B_1+G_1$
2	$1.6A_2+F_2$	$1.25B_2+G_2$
3	$1.6A_3+F_3$	$1.25B_3+G_3$
4	$1.6A_4$	$1.25B_4$
5	$1.6A_5$	$1.25B_5$
6	$1.6A_6$	$1.25B_6$
7	$3.2A_7$	$2.5B_7$
8	$3.2A_8$	$2.5B_8$
9	$3.2A_9$	$2.5B_9$
10	A_{10}	B_{10}
11	$3.2A_{11}+2.2A_{10}$	$2.5B_{11}+1.5\,B_{10}$
12	$3.2A_{12}$	$2.5B_{12}$
$F_1+F_2+F_3=0.55A$ $G_1+G_2+G_3=0.5B$		
2030 Green wedges	Housing space	Business floorspace
Zone	Total 3.2A	Total 2.5B
1	$1.6A_1$	$1.25B_1$
2	$1.6A_2$	$1.25B_2$
3	$1.6A_3$	$1.25B_3$
4	$1.6A_4+F_4$	$1.25B_4+G_4$
5	$1.6A_5+F_5$	$1.25B_5+G_5$
6	$1.6A_6$	$1.25B_6$
7	$1.6A_7$	$1.25B_7$
8	$1.6A_8$	$1.25B_8$
9	$1.6A_9$	$1.25B_9$
10	$1.6A_{10}+F_{10}$	$1.25B_{10}+G_{10}$
11	$1.6A_{11}+F_{11}$	$1.25B_{11}+G_{11}$
12	$1.6A_{12}$	$1.25B_{12}$
$F_4+F_5+F_{10}+F_{11}=1.6A$ $G_4+G_5+G_{10}+G_{11}=1.25B$		

3.4 Model runs

We make the following assumptions in this initial version of the model: there is only one type of household; one type of goods; there are 2 types of housing and 2 types of business floorspace. In this model, different types of buildings have same area of floorspace supply.

3.4.1 Model runs for base year 2000 for Beijing

We first run the model in base year 2000 using parameters in Table 1. We input travel matrices and floorspace constraints based on the observed data of Beijing. The solution of the model in terms of the total demands for housing and business floorspace will match the input supply constraints at equilibrium. Constraints in zone 1-12 are summarised in the following chart.

Table 5. Floorspace constraints for base year 2000

Zone	housing space (million sqm)		business floorspace (million sqm)	
	Type 1	Type 2	Type 1	Type 2
1	7.4	7.4	6.0	6.0
2	10.6	10.6	5.7	5.7
3	16.3	16.3	9.2	9.2
4	3.8	3.8	2.3	2.3
5	6.4	6.4	4.1	4.1
6	17.9	17.9	7.3	7.3
7	7.4	7.4	6.0	6.0
8	10.6	10.6	5.7	5.7
9	16.3	16.3	9.2	9.2
10	3.8	3.8	2.3	2.3
11	6.4	6.4	4.1	4.1
12	17.9	17.9	7.3	7.3

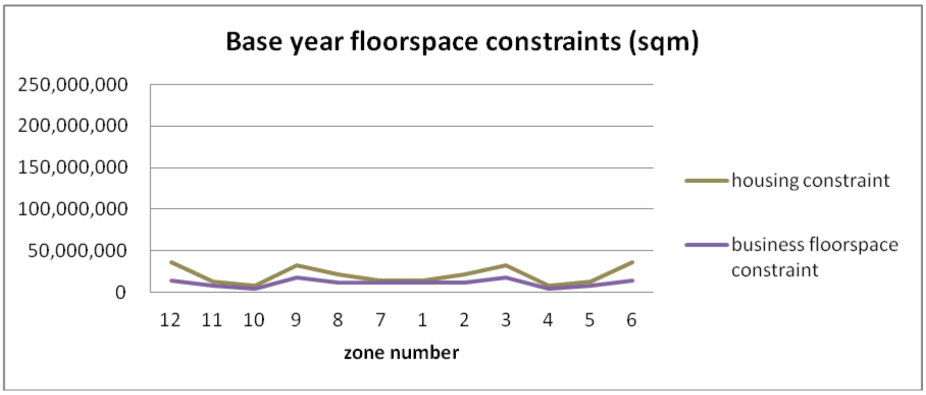

Figure 13. Base year floorspace constraints

The model will output prices, wages, rents, household utilities and industry production in zones. It will also show the locational distribution of households and jobs.

3.4.2 Model runs for 6 scenarios 2030

We then run the model under 6 scenarios in year 2030. Following equations in Table 4, we input zonal constraints for different scenarios based on Beijing's case. Floorspace constraints in each zone to each scenario are summarised in the following pictures and also in appendix.

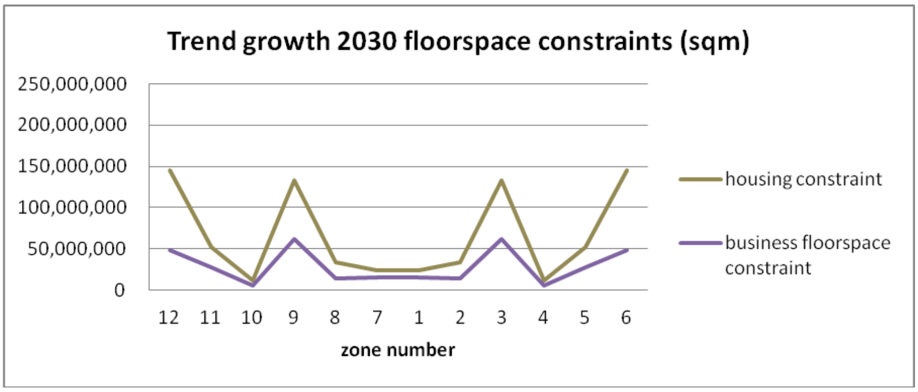

Figure 14. Trend growth 2030 scenario floorspace constraints

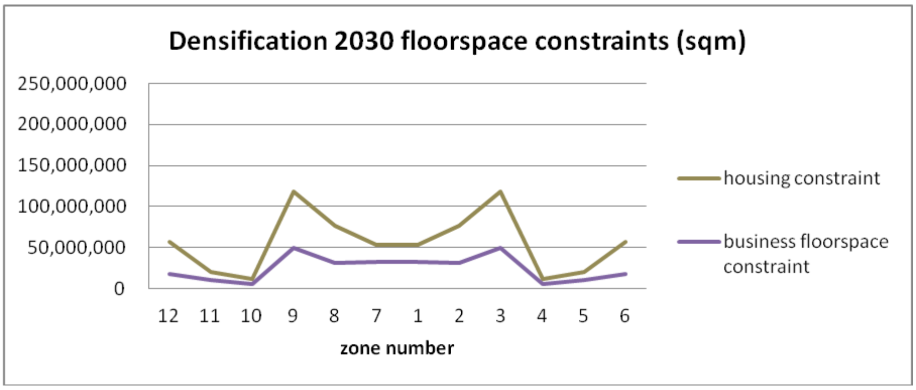

Figure 15. Densification 2030 scenario floorspace constraints

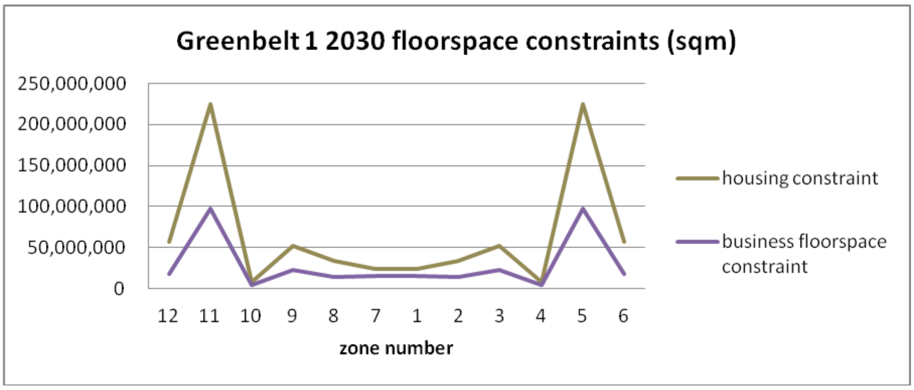

Figure 16. Greenbelt 1 2030 scenario floorspace constraints

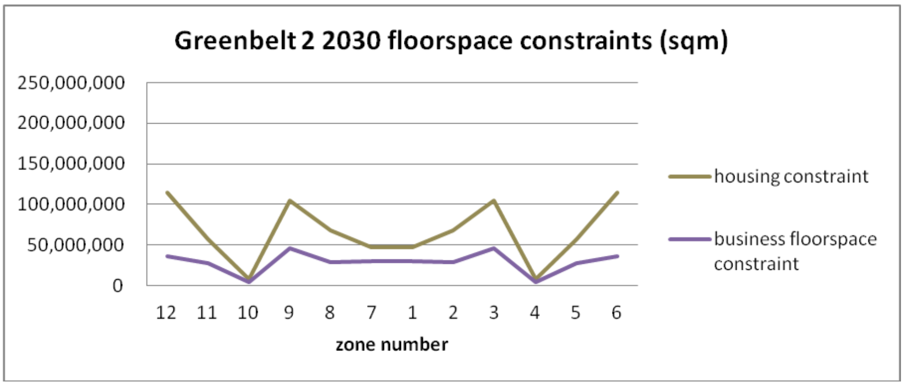

Figure 17. Greenbelt 2 2030 scenario floorspace constraints

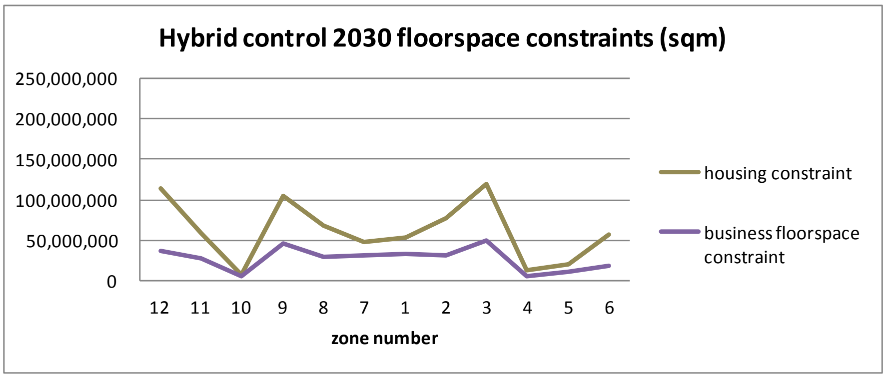

Figure 18. Hybrid control 2030 scenario floorspace constraints

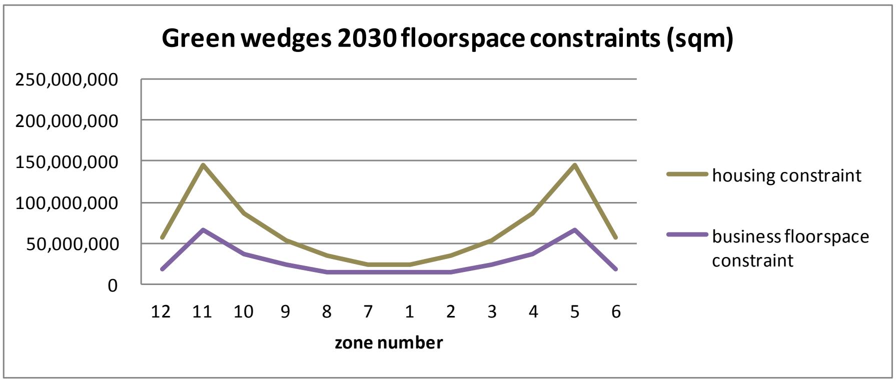

Figure 19. Green wedges 2030 scenario floorspace constraints

Like the base year outputs, the model will reveal differences in prices, wages, rents, household utilities and industry production among different scenarios. It will also show the locational distribution of households and jobs.

3.5 Model results

Table 6 lists main outputs from the simulation.

Table 6. Summary of main modelling results

Scenarios	Base year 2000	2030 trend growth	2030 densification	2030 Green belt 1	2030 Green belt 2	2030 Hybrid control	2030 Green Wedges
Total production(million units)	4697	14512	14084	14446	14541	14318	14744
Average office rent(￥/sqm/year)	174.7	279.0	328.2	279.0	279.2	301.7	279.7
Average product price (￥/unit)	36.8	47.6	49.0	47.8	47.5	48.2	46.9
Average wages (￥/household/hour)	18.0	22.5	22.5	22.4	22.4	22.5	22.1
Average housing rent(￥/sqm/year)	287.1	356.7	419.9	356.6	356.2	385.5	354.7
Average household utility	7.20	7.18	7.14	7.18	7.18	7.17	7.19

Scenarios	Base year 2000	2030 trend growth	2030 densification	2030 Green belt 1	2030 Green belt 2	2030 Hybrid control	2030 Green Wedges
Consumer surplus as percentage of money income %	/	-2.32	-9.68	-3.06	-2.54	-5.95	-0.94
Average commuting time (min/trip)	41.1	40.2	42.0	39.9	38.7	40.3	34.4
Economic mass index	1305	2347	2645	2320	2635	2617	2830

Tables 7-8 list job and population distribution in different scenarios and reveal spatial pattern of the city.

Table 7. Summary of percentage of jobs in zones

Scenarios	Base year 2000	2030 trend growth	2030 densification	2030 Green belt 1	2030 Green belt 2	2030 Hybrid control	2030 Green Wedges
Zones surrounded by the greenbelt (1,2,3,7,8,9)	63%	53%	85%	23%	66%	74%	29%
Greenbelt zones(4,10)	8%	4%	2%	1%	2%	2%	21%
Satellite towns (5,11)	11%	19%	6%	71%	17%	12%	43%
Hinterland (6,12)	18%	24%	7%	5%	15%	12%	8%
Comments on hybrid control					44%jobs in the densification side; 56% in the greenbelt side		

Table 8. Summary of percentage of households in zones

Scenarios	Base year 2000	2030 trend growth	2030 densification	2030 Green belt 1	2030 Green belt 2	2030 Hybrid control	2030 Green Wedges
Zones within the greenbelt (1,2,3,7,8,9)	66%	56%	86%	24%	68%	75%	24%
Greenbelt zones(4,10)	5%	3%	2%	1%	2%	2%	33%
Satellite towns (5,11)	10%	14%	4%	68%	13%	9%	35%
Hinterland (6,12)	19%	27%	8%	7%	17%	13%	7%
Comments on hybrid control					43%households in the densification side; 57% in the greenbelt side		

4. DISCUSSIONS

The modelling results show that the location of floorspace (through construction and redevelopment) and spatial costs (as implied by the urban transport supply) could greatly affect household welfare. In all the scenarios, restricted floorspace supply and rises in congestion will directly impact upon the economic performance of the city as a whole.

The trend growth scenario shows the decentralisation tendency from 2000 to 2030. The percentage of population in the existing main city, which is encircled by the designated greenbelt will fall, and the share of the population in the rest of the municipality (especially the townships and hinterland) will rise. However, because jobs decentralise with households, commuting time does not change greatly. Additionally because travels in the outer suburban areas are faster, commuters can reach longer distances within the same travel times. Wage, price and rents increase mainly proportionally as the income increase. Household utility level sees a drop of 2.32%. Though not preferred by planners, trend growth is the most likely scenario for the city because of development inertia and also the cost of implementation is low.

In the densification scenario, household welfare level drops by 9.68% due to the reduction of household consumption and dwelling floorspace. The policy increases rent substantially and the price goes up as well, because it pushes people and jobs to the expensive central zones and floorspace supply is limited. It shows clearly the trend of concentration under densification policy: the main city (central + inner + outer) attracts jobs and households from towns and hinterland. Commuting time increases due to congestion when compared with the trend growth scenario. Compact city is considered as a sustainable approach against urban sprawl; however it is a costly scenario as tested in the model. The possibility of increasing floorspace in the centre is much lower than in suburbs because of high spatial costs. Therefore, this scenario can be reckoned as less possible to happen.

The stringent greenbelt scenario fulfils the aim of preserving greenfield in the designated greenbelt, as shown in Table 7 and 8 that the number of jobs and populations in greenbelt are controlled at a low level. Average wages, rents and prices are similar to the trend growth scenario. However, the stringent greenbelt scenario presents a very distinct pattern of household and job distribution. Around 70% households and jobs concentrate in the satellite townships while only 25% in the city area within the greenbelt. This scenario is based on an assumption that developing townships and preserving greenbelt is the priority concern of planners and policy makers. However, implementing such a policy will encounter difficulties, because the aim of zero growth in the greenbelt is not easy to achieve and it is a tough task to meet the high demand of floorspace in townships.

Compared with the stringent greenbelt, the loose greenbelt policy shares very similar characteristics in wages, rents and prices. But the spatial pattern is reversed. It indicates a pattern of concentration since more households and jobs relocate in the city from the greenbelt, compared to the stringent greenbelt and trend growth. Although it is assumed that travel time increase within and between satellite towns, the average commuting time decreases compared with other scenarios (except green wedges scenario). Compared to the stringent one, the loose greenbelt scenario also achieves the goal of preserving the greenfield, but at a higher welfare level. In practice, this policy may also be preferred by planners because it allows natural developments in most parts of Beijing and demands fewer interventions.

The hybrid control scenario combines the densification on one side of the centre with loose greenbelt on the other side. It performs similarly to the densification scenario in average economic outputs but this is a less extreme policy. Due to the reduction of floorspace supply, household welfare also sees a drop by 5.95%. This policy also increases rent drastically and price slightly, because of the concentration pattern on one side of the centre: households and jobs are pushed to the central city where floorspace supply is limited. Meanwhile, more than 55% of the total households choose the loose greenbelt side to live and work because there are more floorspace for dwellings and employments. In reality, Beijing’s expansion is likely to be in a hybrid pattern as stated in the master planning. This scenario can be taken as an archetype and in future model, it could involve into a more realistic one.

In the green wedges scenario, populations distribute relatively evenly in the main city, greenbelt and satellite towns. The greenbelt area holds 21% jobs and 33% households in the built-up wedges along transport corridor. Average travel time decreases to 34.4 minutes which is the least compared to other policy options. This TOD pattern attracts people to the built-up wedges which are not far from the main city. This scenario performs the best among all scenarios in household welfare level, for it drops by only 0.94% from 2010, which is the lowest, due to increase of household consumption and leisure time. Implementing such a policy requires a huge amount of public investment in infrastructure; however, investment in public transport is currently the preferred strategy of the policy makers in Beijing.

Data summarised in Table 6 shows that compared with base year 2000 equilibrium, none of the proposed scenarios is able to increase consumer surplus as population goes up. But the last scenario could maintain the reduction at a very low level. When comparing between 2030 scenarios, the green wedges scenario sees least decrease of household utility level while densification scenario sees the largest drop. In practice, densification scenario is also considered as costly while green wedges scenario seems to have the greatest potential to deliver Beijing's growth with the least negative effects upon household welfare.

5. CONCLUSIONS

This model quantifies impacts of policies on individual time periods. The differences of economic indices from modelling results prove that the precise physical forms of fringe area development do significantly affect the whole municipality in economic terms. Wage, rent, price and commuting time change due to the policy levers, and household welfare will be affected. Alternative proposals that have seen fewer applications historically (for example various of options of green wedges) should be considered carefully.

The model proposed in this paper is a parsimonious model and can reveal the basic development trends of policies with fairly small number of parameters. Obviously this model needs to be extended to reflect the socio-economic, land use and transport context of Beijing in greater granularity. Empirical work is on-going which is crucial to provide the full evidence base.

In future work, we will incorporate the time dimension into the model which can link individual time period and recursively predict policy performance. Furthermore, the social and environmental assessments such as carried out in Echenique et al. (2012) may be incorporated in this model for wider assessment of urban sustainability.

APPENDIX

Table 9. Dwelling floorspace constraints in zones (km^2)

	Base year 2000	2030 trend growth	2030 densification	2030 Greenbelt 1	2030 Greenbelt 2	2030 Hybrid control	2030 Green Wedges
1	14.8	23.7	53.8	23.7	47.3	53.8	23.7
2	21.1	33.8	76.9	33.8	67.6	76.9	33.8
3	32.7	132.5	118.8	52.2	104.5	118.8	52.2
4	7.6	12.1	12.2	7.6	7.6	12.2	86.4

	Base year 2000	2030 trend growth	2030 densification	2030 Greenbelt 1	2030 Greenbelt 2	2030 Hybrid control	2030 Green Wedges
5	12.8	52.0	20.5	224.7	57.7	20.5	145.9
6	35.8	145.3	57.3	57.3	114.6	57.3	57.3
7	14.8	23.7	53.8	23.7	47.3	47.3	23.7
8	21.1	33.8	76.9	33.8	67.6	67.6	33.8
9	32.7	132.5	118.8	52.2	104.5	104.5	52.2
10	7.6	12.1	12.2	7.6	7.6	7.6	86.4
11	12.8	52.0	20.5	224.7	57.7	57.7	145.9
12	35.8	145.3	57.3	57.3	114.6	114.6	57.3

Table 10. Business floorspace constraints in zones (km^2)

	Base year 2000	2030 trend growth	2030 densification	2030 Greenbelt 1	2030 Greenbelt 2	2030 Hybrid control	2030 Green Wedges
1	12.0	15.1	32.4	15.1	30.1	32.4	15.1
2	11.5	14.4	31.0	14.4	28.7	31.0	14.4
3	18.4	61.8	49.7	23.0	46.1	49.7	23.0
4	4.6	5.7	5.7	4.6	4.6	5.7	36.9
5	8.1	27.3	10.2	97.9	27.2	10.2	65.6
6	14.6	48.8	18.2	18.2	36.4	18.2	18.2
7	12.0	15.1	32.4	15.1	30.1	30.1	15.1
8	11.5	14.4	31.0	14.4	28.7	28.7	14.4
9	18.4	61.8	49.7	23.0	46.1	46.1	23.0
10	4.6	5.7	5.7	4.6	4.6	4.6	36.9
11	8.1	27.3	10.2	97.9	27.2	27.2	65.6
12	14.6	48.8	18.2	18.2	36.4	36.4	18.2

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