# Alternative Configurations of Beijing's Greenbelt: New Insights from a Recursive Spatial Equilibrium Model

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## Abstract

Greenbelts are considered a key instrument for halting pancake-like urban expansion and providing a healthier urban environment. However, attempts to establish greenbelts in Beijing tended to falter: its first greenbelt of the 1990s disappeared under the urban expansion and its second is under a similar threat. In this paper we use a Recursive Spatial Equilibrium Model to simulate urban growth which not only represents the equilibrating interactions between work, living and travel but also the temporal dynamics of urban land expansion and building stock growth. This model builds upon 3 cross-sectional models for the year of 1990, 2000 and 2010. Alternative historic-if scenarios for 1990-2000 and 2000-2010 are tested. The model results assess the economic performance of the alternative scenarios and suggest that the configuration and timing of large urban green space, such as the greenbelt, have significant impacts on a city's economic performance. The new insights point to a radical reconsideration of the design of strategic urban green spaces in fast growing cities.

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# 1. Introduction

## 1.1 Background

A fringe of a city is a transitional zone 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. For example, in the UK greenbelt policies have existed for more than 70 years to control the expansion of London and many other cities (Hall 1973); urban growth boundary policies have a long tradition in the United States (Staley et al. 1999; Jun 2004).

However, planners in the emerging economies are often discouraged by the fact that policies from the developed country cities, such greenbelts do not lead to the same historic outcomes. Beijing is in many ways a typical example of the fast growing cities which attempt to establish a greenbelt for mainly improving citizen's access to green space and the functioning of the eco-system services.

With rapid economic growth, Beijing accelerated its development and annual population growth rate has reached 3.8% (from 2009 to 2013) and overall population has reached 21.1 million in 2013 (Beijing Bureau of Statistics 2014). The built-up area has been expanding rapidly from 100.2 km2 in 1950 to 1210.2 km2 in 2005 following a concentric pattern of expansion (Figure 1).

The First Greenbelt was introduced in 1994 as an integral part of the decentralisation concept in Beijing Master Plan 1992. 240 $km^2$ of green areas around the fourth ring-road of Beijing were designated as the First 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 & Long 2010).

The Second Greenbelt was introduced in 2003 and emphasised in Master Plan 2004-2020, with a designation of 1556 $km^2$ of green areas between the fifth and sixth ring-roads. New towns beyond the Second Greenbelt are designed in the Master Plan 2004-2020 to contain overspilled population. This policy had some effects as the total green area increased from 366 $km^2$ to 566 km2 from 2001 to 2008 (Gan 2012). However, this number is still lower than the original total green area in 1990s which was 757 $km^2$ and is far from the policy aim.

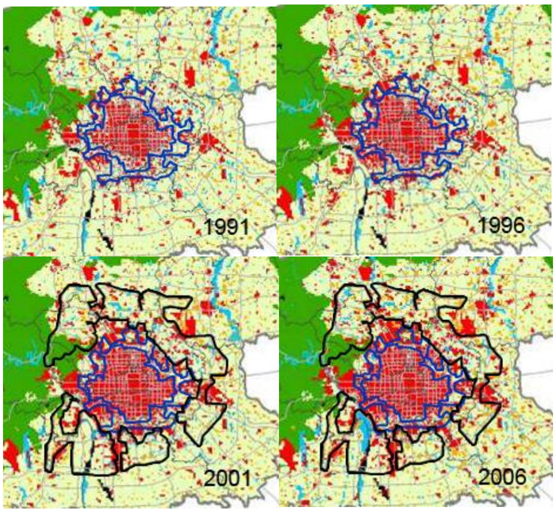



**Figure 1.** Urban land use change before and after greenbelt policies Source: (Long et al. 2012)

As economic, environmental and social conflicts at the urban fringe have intensified, "stop concentric expansion" has been emphasised in recent Mayor's statements. But the reasons underlying the persistent pancake-style expansion have not been systematically explored.

## 1.2 Modelling urban fringe development policies

The existing literature focuses on justifying the greenbelt from an environmental perspective, and has not considered the economic and social equity impacts beyond qualitative statements. Most of them emphasise the difficulties of putting it into practice: government is facing challenge of providing displaced farmers adequate social welfare (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 (Tan 2008). The persistent difficulties in implementing the greenbelt plans have raised the awareness of the impact of a greenbelt on job and residential location distribution, land price and travel patterns. However, in Beijing there are few practical tools that are capable of assessing the economic and social impacts in a systematic way.

Urban models are often used to predict policy performances in urban planning in developed countries (Batty 2009; Wegener 2014). 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 impacts of greenbelts. Partial equilibrium models are used to quantify greenbelts' amenity value and the impacts on land price (Lee & Linneman 1998; Knaap 1985; Nelson 1986; Nelson 1988). Lee and Fujita (1997) added human behaviour to the spatial equilibrium model to examine the relationships between amenities generated by a greenbelt and its efficient location. Jun & Hur (2001), Bae & Jun (2003) developed Lee and Fujita's mono-centric model into a multi-centric model to test the changes of shopping and residential locations in response to greenbelt.

In 2007 Anas developed a 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 & Liu 2007). Based on this model, Anas wrote up three articles (Anas & Rhee 2006; Anas & Rhee 2007; Anas & Pines 2008) to compare performance of stringent greenbelt versus congestion tolls. They casted doubts on greenbelts and concluded that congestion tolls can shrink city size by relocating economic activities while greenbelt of any stringency can be inefficient.

Anas' approaches to model the greenbelt is for discrete time horizons and can predict the performance of a greenbelt on the end state equilibrium. However, as a large scale urban policy, greenbelts take long term to shape itself and dynamically change over time with incremental interventions accompanied by encroachment. For example, the performance of Beijing's first greenbelt was assessed in a decade after established, and the second greenbelt was put forward as a remedy since. Therefore, it is important to incorporate the time dimension when considering the long term effects of greenbelt policies.

In this light, we will use a Recursive Spatial Equilibrium model (Jin et al. 2013) to test the performance of greenbelt policies of Beijing. This model not only examines the greenbelt intervention on urban economy on individual time period, but also examines dynamics of people and investment in response to economic indices. Details of this model is found in Jin, Echenique, Hargreaves (2013).

### 1.3 Aims of the paper

This paper uses a newly assembled dataset for the urban land use and transport development between 1990 and 2010 to establish a recursive spatial equilibrium model. This model can quantify the performance of alternative configurations of greenbelts. The approach is intended for (1) validating a new tool for guiding sustainable urban expansion and (2) gaining insights into how to reshape future urban expansions in emerging economies that are half-way towards urbanisation.

We first calibrate a 130-zone recursive spatial equilibrium model using observed data for 1990-2010 which covers the years when two greenbelt policies were launched (1994, 2003). Alternative historic-if scenarios for 1990-2000 and 2000-2010 that have the same amount of growth but different configurations of urban expansion are tested. Analyses are followed by assessing spatial patterns of jobs and residents, production costs, consumer welfare, rents, prices, and wages in different scenarios.

We deliberately use the historic-if scenarios so as to understand and validate the model in terms of spatial land use and transport demand elasticity over time. This gives a more robust empirical basis for model simulation results, especially under rapid and transformative urban change. The use of historic-if scenarios also provides an opportunity to discuss the results with practitioners and policy makers who are interested in reflecting the experience of urban expansion over the last two decades.

# 2. Methodology

## 2.1 Cross-sectional spatial equilibrium model

### *2.1.1 Producers, consumers and location choice*

Following the tradition of Anas and Liu (2007) the models for producer and consumer behaviour follow a parsimonious design. This allows the users of the model to understand and check easily the causal relationships. The model does not currently include explicit agency of developers or government, although these can be added at a later date which will result in a more complex model to calibrate and use. The choice of this structure is to highlight the key interactions that are most relevant to the broad thrust of urban development and its impact on production and consumer welfare (Anas & Liu 2007; Jin et al. 2013).

The geographic space of the city is divided into discrete but contiguous areas (i.e. model zones). The choice of location is modelled in terms of model zones. Urban development is represented in terms of changes in the stock of housing and business floorspace and in the multimodal transport network which are input into the model by model year. Taxes are not modelled explicitly; instead, the model assumes that the city balances its consumption with its production, and any increase in the property sales/rental income is shared equally among all households. There is one type of composite goods and services. In other version of the model, more types of goods and services have been simulated, so as imbalances of imports into exports from the city. However, those additional features of the model do not seem to alter the main conclusions reached here.

- Producers

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

$$\mathrm{X}_{\mathrm{rj}} = E_{rj}(\sum_{\forall f} L_{rjf}^{\theta})^{\frac{\delta}{\theta}}(\sum_{\forall b} B_{rjb}^{\xi_1})^{\frac{\omega}{\xi_1}}$$

In this hybrid Cobb-Douglas CES function, primary inputs are labour force L and industrial floorspace B. E is scale parameter. This function is rendered constant returns by $\delta+\omega=1$. F represents labour types and 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, subject to maximising their individual households' utility. Each consumer household first decides where to be employed. Then he/she 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:

$$\mathrm{U}_{\mathrm{ijk}} = \alpha \ln(\sum_{\forall k} Z_{ijk}^{\eta_f})^{\frac{1}{\eta}} + \beta \ln(\sum_{\forall Q} q_{ijQ}^{\xi_2})^{\frac{1}{\xi_2}} + \gamma \ln L_{leisureij} + \mu_{ij}$$

Z is the total amount of goods and service a consumer can consume; q is the floor area of his residential place and Lleisure 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. $\mu ij$ is an idiosyncratic utilities which represents unobserved factors. $\alpha+\beta+\gamma=1$.

- 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 $\mu ij$ is Gumbel distribution with dispersion parameter $\lambda$, the probability P of locational choice can be derived through a discrete choice logit model:

$$\mathrm{P}_{\mathrm{ij}} = \frac{\mathrm{S}_i \exp \lambda(U_{ij} - \mathrm{T}_{\mathrm{ij}} + \mathrm{ZAttr}_{ij})}{\sum_{\forall (st)} S_s \exp \lambda(U_{\mathrm{st}} - \mathrm{T}_{\mathrm{st}})}$$

$$\sum_{\forall ij} P_{ij} = 1$$

T is generalised transport cost. ZAttr is a residual zonal attractor to be fitted in model calibration through matching the model predicted location choices to the observed.

#### *2.1.2 Spatial equilibrium conditions*

Following standard assumptions, 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 housing and business floorspace stock constraints. A zero profit condition is set for producers in an open competitive market. The market is zero excess demands in labour market and product market. In labour market, total working hours demand equals total non-leisure hours minus commuting and shopping travel time. In the product market, total goods and services produced equal total goods and service consumed by households.

### 2.2 Modelling urban change through time

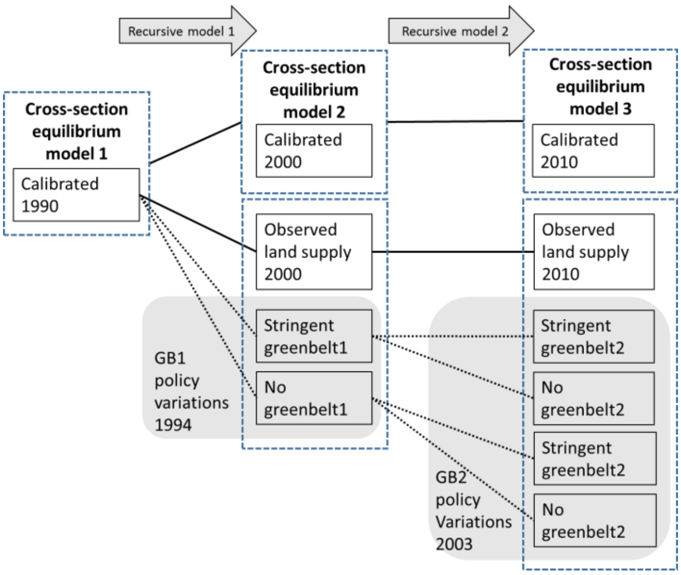



**Figure 2.** Model structure

This model covers two decades and consists of 3 cross-sectional spatial equilibrium models: 1990, 2000 and 2010, interfacing with a multimodal transport model. The modelled years coincide with population census years for maximum data availability. Two greenbelt policies (Greenbelt1 in 1994 and Greenbelt2 in 2003) are simulated in the recursive models along with a number of historic-if scenarios.

We first calibrate the cross-sectional equilibrium models for year 1990, 2000 and 2010 individually. In particular the residual zonal attractors are fitted by year using the observed locational choices. At this stage, the individual yearly models are verified by comparing the model predicted locational choices with the observed data. Secondly, we validate the yearly models by using an earlier year's model to predict the change in the decade to come, e.g. using the model parameters calibrated for 1990 to predict what the choices of job and residential locations in 2000. Thirdly, once the yearly models are shown to have a reasonable capability for predictions, we test alternative, historic-if scenarios. This include two such alternatives for 1990 – one that has a more stringent greenbelt implementation, and the other without any greenbelt interventions. This is then followed by four historic-ifs, each of two sets stemming from those for year 2000 (Figure 2).

In those tests above, the floorspace inputs are derived recursively for each pedigree of scenarios. This has provided the first recursive connections between the cross-sectional model tests. It is possible to link the cross-sections further through mover-stayer type demographic inertia, which we will not attempt in this paper given its complexity.

## 3. Case Study

### 3.1 Zone classification

The model divides Beijing into 130 zones according to the existing districts and transport links. We then classify the 130 zones of Beijing into 6 types. Type 100 is the centre of Beijing which is defined as the zones encircled by the Greenbelt1. Type 1 is the Greenbelt1 area while Type 2 is the Greenbelt2 area. Type 10 represents the 10 fringe settlements stated in the Greenbelt1 policy that would be intensively developed. Type 20 is the new towns beyond the Greenbelt2. Type 0 represents the rest zones. Boundaries of different zone types do not 100% comply with the Greenbelt1 and 2 policy because zones are defined by transport and administrative boundaries. But this zoning is accurate enough to show the ring effects.

For each type in each scenario, we define a specific growth rate for business and housing floorspace from base year 1990. The scenarios in the same year have the same demographic settings: the same number of households and jobs, and the same family size and income, and the same total floorspace constraints. Differences are represented only in the location of floorspace supply.

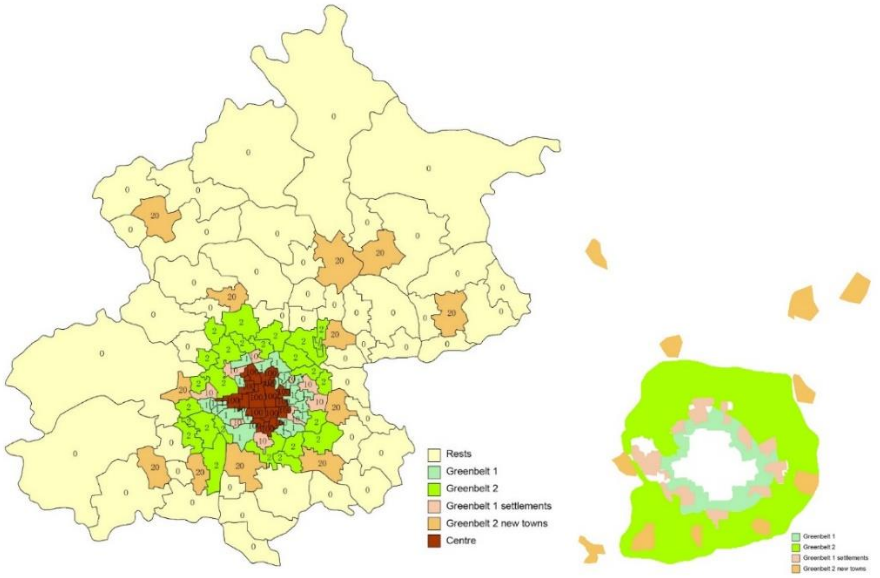



**Figure 3.** Left: zone classifications. Right: master plan of Greenbelt1 and its fringe settlements; Greenbelt2 and new towns

### 3.2 Model calibration

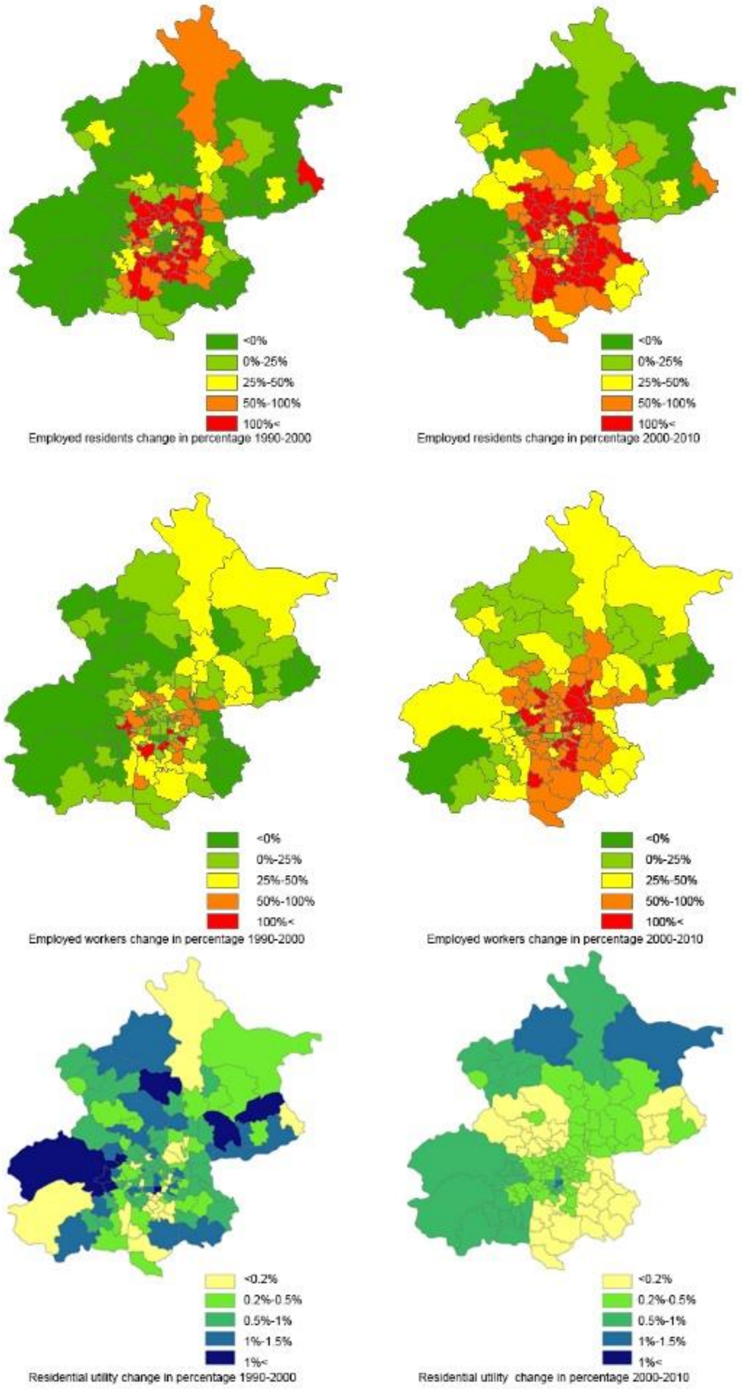
We make the following assumptions in this initial version of the model: there is only one type of household (those containing currently employed persons), one type of housing floorspace, one type of business floorspace and one type of composite goods and services.

We prepared three cross-sectional datasets for model calibrations. Year 1990, 2000 and 2010 historic patterns are calibrated according to the zonal numbers of employed workers and residents observed data. 2000 and 2010 data are from the yearbook and census. 1990 data are calculated based on some boundary conditions obtained from yearbook and census data, because such numbers do not exist in early years. Price levels are all converted to year 2010. The models calibration procedure is successful in adjusting the zonal attractiveness to fit the observed data of zonal numbers of employed workers and residents, as well as respecting the input supply constraints.

The calibrated models provide information about the spatial variations in prices, wages, rents, household utilities and production levels over two decades and the effects of the greenbelt interventions. Such numbers are omitted in current data.

**Table 1.** Summary of main model inputs and results

| **Inputs** | **1990** | | | **2000** | | | **2010** | | |
|---|---|---|---|---|---|---|---|---|---|
| Total number of residents (thousands) | 6271 | | | 7116 | | | 11805 | | |
| Total number of jobs (thousands) | 6271 | | | 7116 | | | 11805 | | |
| Income per household per year (￥) | 3871 | | | 8641 | | | 22246 | | |
| Persons per household | 3.20 | | | 2.90 | | | 2.45 | | |
| **Outputs** | **Ave** | **GB1** | **GB2** | **Ave** | **GB1** | **GB2** | **Ave** | **GB1** | **GB2** |
| Average office rent(￥/sqm/year) | 61 | 61 | 53 | 136 | 139 | 118 | 350 | 359 | 302 |
| Average product price (￥/unit) | 8.02 | 8.02 | 7.21 | 17.70 | 17.78 | 15.76 | 45.22 | 45.47 | 39.89 |
| Average wages (￥/household/hour) | 2.01 | 2.04 | 1.86 | 4.43 | 4.49 | 4.04 | 11.32 | 11.44 | 10.18 |
| Average housing rent (￥/sqm/year) | 78 | 75 | 68 | 116 | 128 | 105 | 244 | 271 | 227 |
| Average household utility | 7.907 | 7.929 | 7.928 | 7.978 | 7.973 | 7.985 | 8.008 | 8.002 | 8.006 |


<0%
0%-25%
25%-50%
50%-100%
100%<
Employed residents change in percentage 1990-2000
<0%
0%-25%
25%-50%
50%-100%
100%<
Employed residents change in percentage 2000-2010
<0%
0%-25%
25%-50%
50%-100%
100%<
Employed workers change in percentage 1990-2000
<0%
0%-25%
25%-50%
50%-100%
100%<
Employed workers change in percentage 2000-2010
<0.2%
0.2%-0.5%
0.5%-1%
1%-1.5%
1%<
Residential utility change in percentage 1990-2000
<0.2%
0.2%-0.5%
0.5%-1%
1%-1.5%
1%<
Residential utility change in percentage 2000-2010

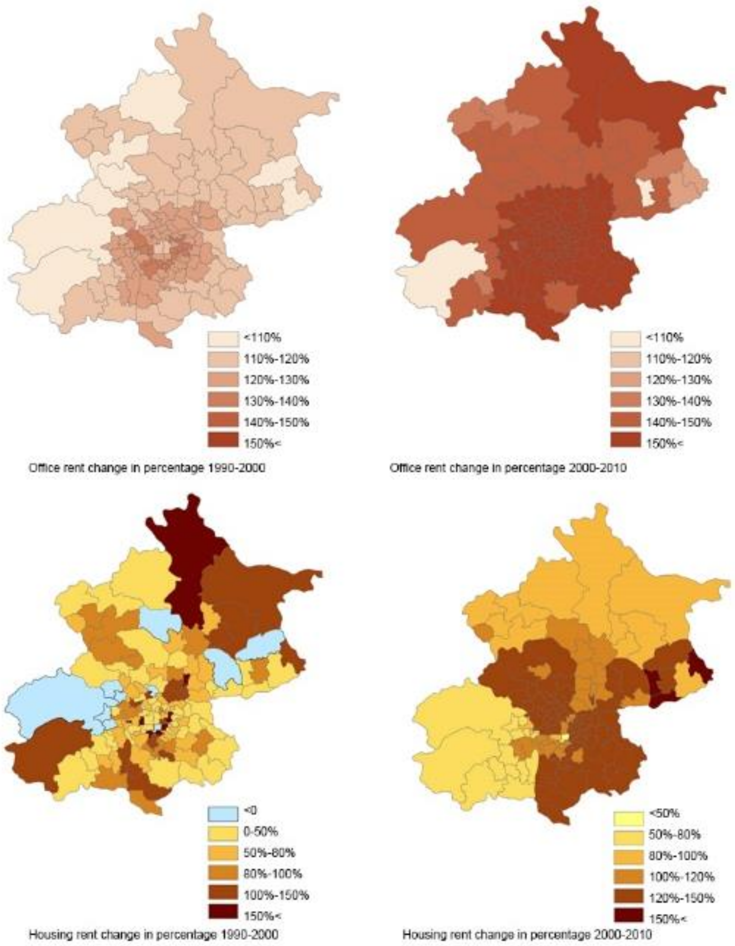



**Figure 4.** Employed residents, employed workers, utility, office rent and housing rent change in percentage 1990-2000, 2000-2010

The 3 cross-sectional calibrations reveal some unknown indices in data. The restrictions of land supply arising from the greenbelt interventions have led to a slowed-up increase in rent: In 1990, rents of the Greenbelt1 area stayed similarly as the regional average but from 2000, the price related index transcended the regional average. Greenbelt1 zones became an expensive area. A ring effect can be witnessed in the demographic patterns: residents intended to move outwards to Greenbelt1 from 1990-2000 and then spread into Greenbelt2. Jobs show a more centralised pattern as most new jobs stayed in the centre from 1990-2000 and spread to the east during 2000-2010.

### 3.3 Model test runs

#### *3.3.1 Application 1: data verification and model validation*

Due to the independency of the cross-sectional equilibrium models, this model can predict forward (from 1990-2000-2010) or backward (2010-2000-1990). This characteristic gives us a tool to verify the zonal data of 1990, as they are estimated initially because of the limit of data release.

We first run the 2000 calibrated model, predicting back to year 1990. Secondly we run the 2010 calibrated model, predicting back to 1990 as well. The third step is to compare the 2 groups of modelling results of employed workers and residents with the 1990 estimated data. Then we can update the zonal 1990 data and run the model forward from 1990 to 2000 and from 1990 to 2010 for validation. Then, we compare the predicted zonal number of residents and workers with observed 2000 and 2010 data, in order to test how well the calibrated 1990 zonal attractiveness and updated data can fit 2000 and 2010 patterns. This process can be done several times until we obtain satisfactory base year data.

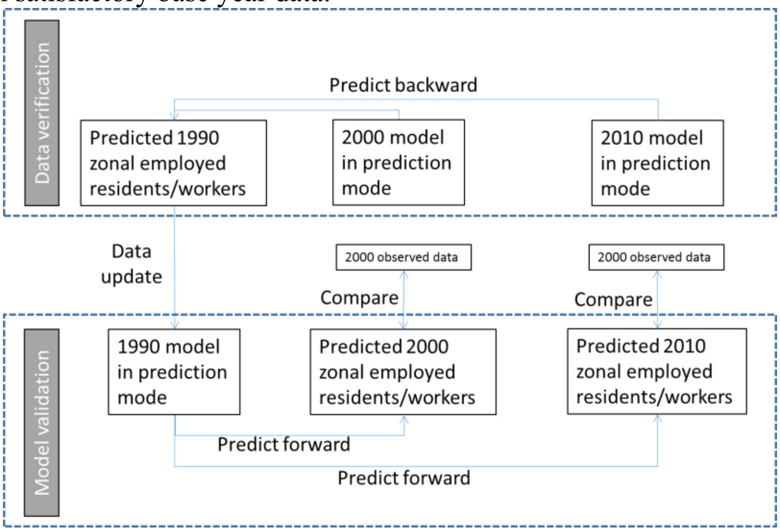


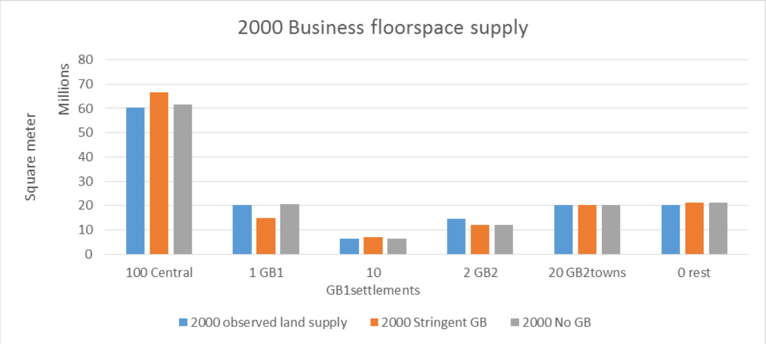

**Figure 5.** Data verification process

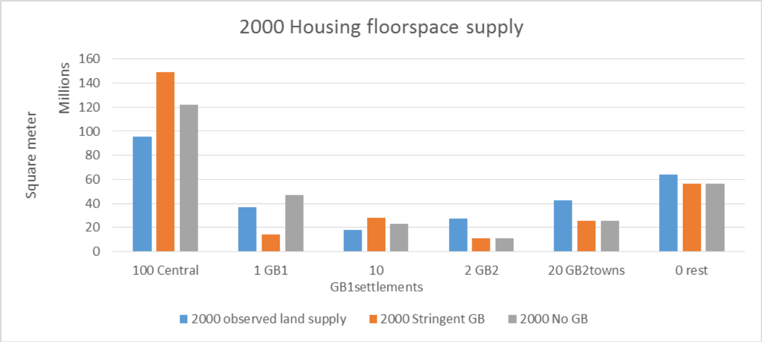
After several runs, most of the observed numbers of employed workers and residents fit the number predicted from 1990. For those zones that have substantial difference in the number of employed residents and workers in 2010 validation results, we look back to policy variance to interpret them. Therefore, we currently use this 1990 model as base to predicted historic-ifs for year 2000 and year 2010.

### *3.3.2 Application 2: test historic-if scenarios*

For year 2000, historic-if scenario 1 represents a stringent greenbelt plan with intensively developed fringe settlements, which means only 2% growth in greenbelt from 1990 to 2000 according to the Greenbelt1 policy. Scenario 2 represents a “no greenbelt” pattern, in which we deliberately eliminate the growth control in the designated greenbelt area. For the zones outside Greenbelt1 in both scenarios, natural growth rate of 5% will be applied.

The floorspace constraints of 2010 scenarios are supposed to be calculated endogenously from the 2000 modelling results of land prices and building stocks through recursive components. However, at this stage we exogenously define 2010 floorspace inputs. Scenario 1 is to implement a second stringent greenbelt in addition to the first one, so that the city will have an expanded green system; on the contrary, Scenario 2 is based on the first stringent greenbelt but no further action of second greenbelt will be put forward. Scenario 3 is to implement a stringent Greenbelt2 based on the condition that no Greenbelt1 has been designed; scenario 4 follows the “no greenbelt” policy and still does nothing to control expansion. For the zones outside Greenbelt2, natural growth rate of 5% will be applied. Floorspace variances in historic-ifs are summarise in the following figure.



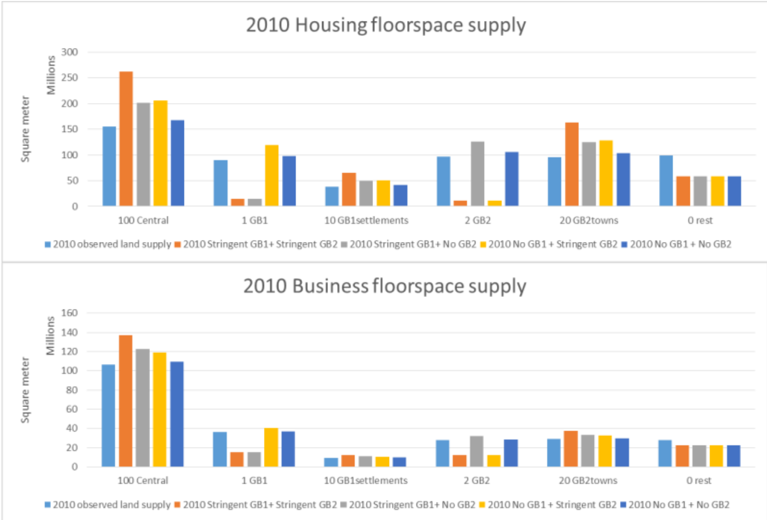


**Figure 6**. Floorspace variances in historic-ifs

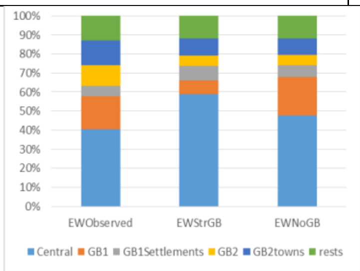
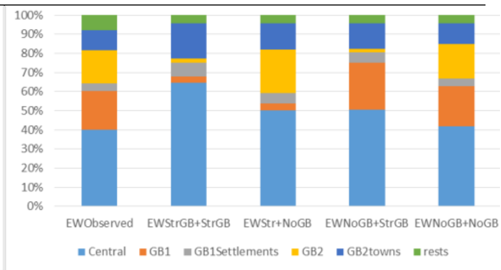
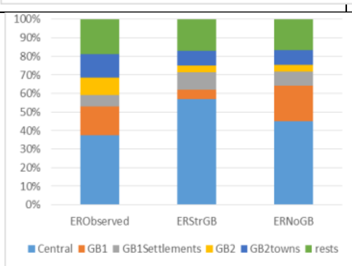
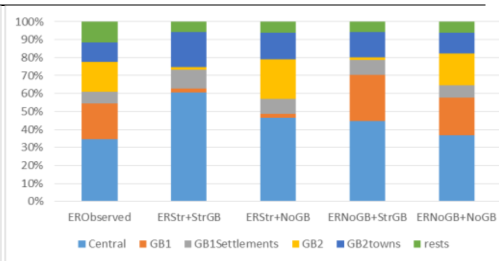
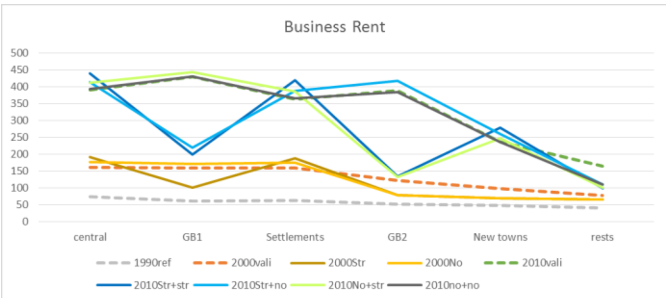
As the 1990 prediction mode model has been validated, we input the parameters and zonal attractiveness of 1990 to predict the 2 historic-if scenarios in year 2000 and the 4 historic-if scenarios in year 2010. Floorspace constraints in each zone to each scenario are kept the same in total for the city region. The model will reveal differences in prices, wages, rents, household utilities and industry production. It will also show the predicted new locational distribution of households and jobs.

### 3.4 Comparison among the model tests

Table 2 lists main outputs of the prediction mode. Jobs and households distributions are shown in bar chart. Line chart are the rent patterns.

**Table 2.** Summary of main model results

| | 1990 | 2000 | | | 2010 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scenar-ios** | **reference** | **Ob-served land supply** | **Strin-gent GB1** | **No GB1** | **Ob-served land supply** | **Strin-gent GB1+ Strin-gent GB2** | **Strin-gent GB1+ No GB2** | **No GB1 + Strin-gent GB2** | **No GB1 + No GB2** |
| Total production (million units) | 3985 | 4545 | 4521 | 4528 | 7419 | 7446 | 7377 | 7451 | 7407 |
| Average product | 8.02 | 17.80 | 17.90 | 17.87 | 46.58 | 46.41 | 46.84 | 46.38 | 46.66 |

| | 1990 | 2000 | | | 2010 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scenar-ios** | **reference** | **Ob-served land supply** | **Strin-gent GB1** | **No GB1** | **Ob-served land supply** | **Strin-gent GB1+ Strin-gent GB2** | **Strin-gent GB1+ No GB2** | **No GB1 + Strin-gent GB2** | **No GB1 + No GB2** |
| price (￥/unit) | | | | | | | | | |
| Average wages (￥/house-hold/hour) | 2.01 | 4.42 | 4.41 | 4.41 | 11.30 | 11.28 | 11.29 | 11.27 | 11.28 |
| Average household utility | 7.907 | 7.972 | 7.971 | 7.971 | 7.974 | 7.968 | 7.969 | 7.973 | 7.973 |
| Consumer surplus as percentage of money income % | - | 0 | -0.4% | -0.3% | 0 | -2.5% | -2.1% | -0.4% | -0.4% |
| Employed workers distribu-tion | - |  | | |  | | | | |
| Employed residents distribu-tion | - |  | | |  | | | | |
| Zonal business rent | - |  | | | | | | | |

| | 1990 | 2000 | | | 2010 | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Scenar-ios** | **reference** | **Ob-served land supply** | **Strin-gent GB1** | **No GB1** | **Ob-served land supply** | **Strin-gent GB1+ Strin-gent GB2** | **Strin-gent GB1+ No GB2** | **No GB1 + Strin-gent GB2** | **No GB1 + No GB2** |
| Zonal housing rent | - |  | | | | | | | |

## 4. Discussion

The model results in prediction mode show that the location of floorspace supply as a result of different configurations of greenbelts could greatly affect household welfare, location choices and impact upon the economic performance of the city.

The spatial patterns of 2000 and 2010 with observed land supply are similar to the two No_Greenbelt scenarios: the two greenbelts contained some 40% populations and jobs in 2010. It suggests that the existing greenbelts in Beijing as they stand have not reached the goal of reshaping urban spatial structure. Fringe settlements and new towns did not absorb the overspill population and people intended to live in the existing main city.

A stringent realisation of Greenbelt1 in 2000 would engender further concentration of population and jobs in the existing city. The establishment of Greenbelt2 in 2010 reinforced such effects, as more than 60% jobs and residents remain in the main city. The two scenarios fulfil the aim of preserving greenfields, as number of jobs and population in greenbelts are controlled at a low level. Accordingly, rents in the centre, fringe settlements and towns increase because policies pushes people and jobs to the expensive central zones where floorspace supply is limited. The overall consumer surplus drops 2.5% which is the largest among 2010 scenarios. Greenbelt city may turn out to be a costly economic scenario which may explain why the greenbelt plans met so many difficulties in implementation.

The two hybrid scenarios in 2010 show distinctive spatial patterns due to different greenbelt configurations and policy timings. The stringent_Greenbelt1+no_Greenbelt2 scenario represents a greenbelt in the early days with smaller size. In 1994 when Greenbelt1 was established, development had not yet reached there. Therefore the relocation effects of Greenbelt1 cannot be seen until a decade later. When urban expansion started after 2000, people began to locate beyond the Greenbelt1, seeking for lower rent, price and bigger properties.

The no_Greenbelt1 +stringent_Greenbelt2 scenario represents a bigger size greenbelt in rapid urban expansion. Consequently, development spread into the Greenbelt1 but stopped by Greenbelt2. Modelling results imply greenbelt launched in line with fast developing period is more effective in preventing unwanted urban expansion. Additionally, the sizes of greenbelts also affects travel behaviours. Commuting across the Greenbelt1 is possible but beyond the Greenbelt2 is less possible, given the available transport infrastructure.

At zonal level, rents respond sensitively to floorspace supply: for the free market scenarios (i.e. observed growth and no_greenbelts) it reflects the direct market effects and drops from the centre to the hinterland; for various greenbelt scenarios, the development control has made the greenbelt areas less attractive, which in turn suppresses the rent levels. However, the tests above are still being checked in depth.

## 5. Conclusion and further work

The ultimate aim of this model is to answer what-if questions about future land use policy interventions. However, in this paper we argue that it would be necessary to have an often omitted stage of proper model calibration and validation, i.e. to test systematically the capability and validity of model in providing cross-decade predictions. This is carried out here through testing the model in reproducing the observed growth. Compared with what-if tests of future scenarios, the historic-if tests are simpler to analyse (as they are generally free of the uncertainties in background trends). It is therefore a logical step towards building valid prediction models for future scenarios.

Independent cross-sectional predictions cannot fully show the effects of chronic and large scale land use policy on growth inertia. Time dimension incorporated in equilibrium model enable it to show the time lag between the launch of greenbelt policies and people's response of location choices, and the long-term effect of greenbelts on building stock allocation.

The model applied in this paper is a parsimonious model that is capable of revealing the basic interactions among socioeconomic, land use and transport developments with fairly small number of easy-to-interpret parameters. The model can be extended to reflect the more precise socio-economic, land use and transport context of Beijing in greater granularity.

Nevertheless, the model results can already provide a range of insights into greenbelt-related debates. The analyses suggest that under rapid transformative urban change, the configuration, size and policy timing has a significant impact on the economic performance. Proposals of strict, wide and ring-like greenbelts may not necessarily be the highest performing intervention. Past trends of growth and alternative green space configurations should be more thoroughly investigated. It seems clear that the model provides a unique set of information to understand past patterns of development, which in turn can contribute to designing better performing future configurations.

In further work, we will incorporate further recursive dynamics. Furthermore, the social and environmental assessments may be incorporated for wider assessment of urban sustainability.

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