



**Economic impacts of alternative greenspace configurations
in fast growing cities – the case of Greater Beijing**

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Economic impacts of alternative greenspace configurations in fast growing cities – the case of Greater Beijing

Abstract

Greenspaces at the city scale, like greenbelts, green-wedges or green-grids have become well-known instruments for shaping urban economic activity and land use. The economic impacts of such instruments are complex and hard to measure. This paper addresses one of the rarely studied problems of measuring economic impacts of alternative greenspace configurations in fast growing cities. In such cities, there is an uncertain basis for making such greenspace related decisions, for example the assumptions about the cities' total population and economic activity. Decision makers have few tools to measure and predict the potential economic costs and benefits of alternative greenspace configurations.

We present a new model that allows tracking over time of both non-divisible land use decisions and a multitude of gradual adaptations made by businesses and consumers. The model is applied to Greater Beijing, one of the fast growing cities that is actively exploring alternative greenspace configurations to control urban expansion. The modelling results suggest that compared to the trend-development scenario of no greenspace intervention, a strict greenbelt would decrease the overall consumer surplus in Beijing by \$3.3 billion, while an adaptive mix of green-wedges and green-grid would increase consumer surplus by \$3.6 billion per year in 2030. The adaptive configuration also reduces car journeys by 11% in Beijing. More generally, modelling results show that a flexible design of strategic greenspaces and careful siting of new development around metro stations within the designated greenspaces could benefit consumers and promote sustainable travel.

Key words

Greenspace, Urban Modelling, Recursive Spatial Equilibrium, Land Use Transport Interaction (LUTI), Greater Beijing

Introduction

Designating large urban greenspaces in planning is a frequently adopted means of land use control. The preserved greenspaces are considered key instruments for protecting the ecosystem, creating amenity and recreational spaces, and preventing undesirable expansion. Urban greenbelt, green-wedges and green-grid are alternative configurations that have been implemented. However, their economic impacts are complex and hard to measure. This is

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3 because large urban greenspaces will have impacts on multiple urban markets, for example
4 the land market, labour market, product market and transport market. The impacts of
5 greenspaces on each market are hard to quantify without considering the complex and
6 concurrent interactions among these markets. Meanwhile, large urban greenspaces will have
7 enduring impacts on a city's economic wellbeing. Such impacts are hard to trace over time
8 because of the changing historic background conditions.
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13 The greenbelt is the most common strategic greenspace configuration and is implemented in
14 a large number of cities (Amati 2008; Buxton & Goodman 2003; Kim & Kim 2008; Okata &
15 Murayama 2011; Tang et al. 2007; Carter-whitney & Esakin 2010; Staley et al. 1999). It is
16 considered crucial for shaping compact urban form, stopping urban sprawl (Pendall et al.
17 2002; Staley et al. 1999) and reducing Vehicle-Miles-Travelled (VMT) (Ewing & Cervero
18 2010; Ewing & Cervero 2017). However, for fast growing cities where development demands
19 keep growing beyond existing masterplans, which is often the case, greenbelts could look, at
20 least to some, anachronistic. In cities where urban growth has exceeded their planned targets,
21 greenbelts have been criticised for increasing land value in the existing city centre (Ball et al.
22 2014), encouraging car travel (Rodriguez et al. 2006), and increasing urban congestion
23 (Freestone 2002).
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31 The green-wedges policy is an alternative configuration to the greenbelt and has been
32 proposed or implemented in several cities (Cambridge Futures 2000; Knowles 2012). The
33 idea is to allow developments to radiate from the city centre into the designated greenbelt
34 often along public transport corridors, normally at a relatively high net density, such that
35 urban expansion can better integrate with major public investments like rail or metro. The
36 green-grid is another alternative. The idea is to take a bite out of the greenbelt and transform
37 that into a carefully designed plot for development (Rudlin & Falk 2014). Also, the green-
38 grid idea seeks to connect small pieces of existing greenfield land like small parks and
39 orchards.
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47 Alternative greenspace configurations take a long time to shape. Their governance tends to
48 prefer stability and permanency in their designations. Once they are established, it is very
49 hard to reverse the land use patterns. In fast growing cities, this is problematic. This calls for
50 stronger evidence that can better anticipate different rates of urban expansion. Such a
51 requirement is much tougher than in developed countries with slower growing cities.
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3 However, there are few tools for policy makers to assess alternative greenspace plans on a
4 consistent basis.
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7 For cities that are reviewing greenbelts and/or initiating alternative configurations, a rigorous
8 tool is needed to measure and predict the potential policy impacts, so that the cost of
9 implementing an unpredictable policy may be avoided. This prompts us to develop a new tool
10 for predicting and comparing the performance of alternatives for fast expanding cities. We
11 aim to answer the following questions: What are the short-term and long-term economic
12 effects of different greenspace configurations? Which configuration performs better in terms
13 of economic efficiency and consumers' wellbeing?
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19 **A review of existing methods**

20 Empirical comparisons were conducted to evaluate the performance of established
21 greenspaces in cities in developed economies (Woo & Guldmann 2011; Jun 2004; Giuliano
22 & Narayan 2003; Siedentop et al. 2016). Such studies are based on well-documented data for
23 cross-sectional and cross-city comparisons. For example, Siedentop et al. (2016) compared
24 the land coverage changes of four regions with different levels of greenbelt controls over a
25 decade. However, for cities in emerging economies, such comparisons were hindered by the
26 difficulty in acquiring data.
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32 Partial regression models are commonly used to identify specific economic effects of
33 greenspaces on a single urban market. For example, Lee and Linneman (1998) and Correll et
34 al. (1978) identified amenity value changes as probable consequences from greenbelts or
35 urban growth boundaries. Nelson (1986; 1988), Knaap (1985), Ball et al. (2014) identified
36 land and house price differentials due to land supply constraints. Such studies generally do
37 not specify a model for the housing market in an equilibrium state.
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43 In addition to partial models, feedback and interactions amongst urban markets were
44 established in spatial interaction models, such as in Lee and Fujita (1997), Bae and Jun (2003)
45 and Jun (2011). Lee and Fujita (1997) modelled the interactions among residents, landowners
46 and governments subject to greenbelt locations, and used Herbert-Stevens model for the
47 optimal provision of a greenbelt. Jun (2011) established a random utility-based input-output
48 model with an endogenous land market to test the effects of Seoul's greenbelt on the spatial
49 distribution of population and jobs.
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3 Existing studies have pointed out that greenspaces will have impacts on multiple urban
4 markets, and due to the multitude of concurrent changes of factors in the whole urban system,
5 it is empirically impossible to isolate one urban market from the others (Wegener 2004).
6 Therefore, whole-city models are needed to test the impacts of greenspaces and to reveal the
7 reciprocal connections between transport and land use (Jun 2004; Rodriguez et al. 2006; Woo
8 & Guldmann 2011).
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13 Moreover, for modelling fast growing cities, in addition to evaluating policy performance at a
14 particular cross-section or end-state, the time dimension and path dependency of urban
15 development have become important. This is particularly the case for cities that have to
16 modify their growth plans significantly during fast growing phases.
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20 In this light, we develop a new analytical model which can address the interactions amongst
21 various urban markets on a whole-city scale, and the dynamic nature of urban transformations
22 over time. The model will predict the economic impacts of greenspaces on four major urban
23 markets: the day-to-day adaptations of the transport market, the short-to-medium-term impacts
24 on labour and product markets, and the long-term evolution of housing and business
25 floorspace.
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31 **The theoretical model**

32 The analytical model is a new variant of the Land Use and Transport Interaction (LUTI)
33 model, which combines the principles of spatial equilibrium with non-equilibrium urban
34 dynamics. LUTI models have been applied in cities around the world to provide an evidence
35 base for planning decisions. For systematic reviews of LUTI models in application, see
36 articles by Batty (2009), Wegener (2004; 2014), Iacono et al. (2008). For the LUTI model
37 tradition that we follow in this paper, long-term and repeated applications in cities such as
38 Bilbao in Spain, Santiago in Chile, and Cambridge and London in the UK have been effective
39 in supporting the formulation of policies in the last forty years (Research Excellence
40 Framework 2014).
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47 Traditionally, LUTI models assume an equilibrium between supply and demand in the land
48 use and transport markets (Echenique 2011; Williams 1994; Anas & Liu 2007), while recent
49 development of LUTI models consider the different speeds of urban changes and concentrate
50 on their outcomes over time (Wegener 2004; Simmonds et al. 2013). Based on these
51 substantial contributions, we select a combined equilibrium-recursive structure (Jin et al.
52 2013) for our model representation, in which the end state of one time period serves as the
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3 initial state of the subsequent time period: the equilibrium component captures short-to-
4 medium-term adaptations of travel and location choices, while the recursive component follows
5 up long-term development trajectories under different greenspace configurations.
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8 The equilibrium component is developed based on a generic LUTI framework. The land use
9 markets are further developed into two sub-models (see Figure 1; equations are presented in
10 Supplementary Material 1): The Spatial Equilibrium Model, which explores the employment-
11 related urban activities; the Non-commuting Travel Demand Model, which explores the non-
12 commuting urban activities.
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17 The Spatial Equilibrium Model (built in Matlab scripts following the RELU-TRAN structure)
18 predicts the employment and residential locations under a simultaneous equilibrium in the
19 production market, labour market and real estate market. The core of this sub-model includes
20 a hybrid Cobb-Douglas Constant Elasticity of Substitution (CES) functions for producer
21 choices for production inputs and consumer choices for consumption (Anas & Liu 2007;
22 Anas & Rhee 2006; Jin et al. 2013). It predicts employment-residence locations based on a
23 logit form discrete choice model, which facilitates the non-commuting activity generation and
24 transport demand estimation. It also offers the starting point of the development trajectories
25 and defines the inertias and trends for the next decade.
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32 The Non-commuting Travel Demand Model (built in the MEPLAN-LUS module) takes the
33 prediction of employment-residence locations from the Spatial Equilibrium Model, and
34 predicts locations of non-commuting urban activities based on an input-output social
35 accounting matrix and market constraints. It generates non-commuting travel demand for the
36 transport simulation.
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41 The transport market is represented by a Strategic Transport Model, which is a trip-based
42 model. This model is built in the MEPLAN-TAS module. It takes the travel demands, namely
43 trip ends, from the two land use sub-models, splits traffic flows into travel modes, and assigns
44 them on the transport network. By doing this, it gives the travel disutilities between origin-
45 destination (OD) zone pairs back to the two land use sub-models, which is the bridge for
46 land-use and transport interaction.
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51 The Spatial Equilibrium Model, Non-commuting Travel Demand Model, and Strategic
52 Transport Model form the equilibrium component and represent one cross-sectional year of
53 simulation. The Recursive Dynamic Model (built in Matlab script, following the MEPLAN-
54 LUS structure) links several cross-sectional years and updates the floorspace supply and
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3 transport network for the next cross-sectional year, based on endogenous outputs from the
4 spatial equilibrium component that represents market inertia and exogenous policy
5 interventions.
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8 The modelling package starts with a cross-sectional base year run. In the base year, the model
9 runs under calibration mode. It receives two main inputs: the quantities of housing and
10 business floorspace, and the travel disutilities between all OD zone pairs. Model predictions
11 (numbers of jobs, residents, production value, demands for floorspace, rents and wages) are
12 compared with known zonal quantities and prices from published statistics, such as censuses
13 and travel surveys, to refine the parameters. The parameters are validated and re-estimated.
14 The validation requires a second observed cross-sectional year to test the suitability of the
15 calibrated parameters. After validation, the parameters are then used for prediction.
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22 The model outputs show the zonal average economic productivity, household utility and
23 travel behaviour by socio-economic group under alternative greenspace configurations. The
24 main outputs include zonal population and employment numbers, rents, household utility by
25 socio-economic group, the floorspace stock, travel times, distances and costs by socio-
26 economic group and by travel purpose, and the travel mode share. The outputs provide a
27 consistent basis for comparing economic impacts of alternative greenspace configurations.
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34 [INSERT FIGURE 1 HERE]
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39 **Model application – which greenspace configuration for Greater Beijing in 2030?**

40 We test the theoretical model on one of the fastest growing cities - Greater Beijing. It is a
41 typical example of a fast growing city which intends to establish strategic greenspaces to
42 achieve environmental benefits and control undesirable urban expansion.
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46 ***Policy context and geographical specification***

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49 Beijing introduced its first greenbelt in 1994 in order to stop the successive urban expansion
50 wave. The second greenbelt was introduced in 2003 and emphasised the latest Beijing
51 Masterplan of 2016 – 2035. Studies have shown that Beijing's greenbelt policies increased
52 tree canopy cover (Yang & Zhou 2007), encouraged tree planting on village brownfield (Tan
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3 2008), preserved the continuity of large pieces of greenspaces (Gan 2012), and safeguarded
4 water bodies and forest (Han & Long 2010).
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7 The establishment of greenbelts are well-grounded by their environment benefits, but the
8 promoters were frustrated by the difficulties in policy implementation. In fact, data show that
9 the percentage of greenfield land remaining from the proposed first greenbelt is less than 11%
10 (Wang 2015). In the second greenbelt, land that is available for greenery reduced from 412
11 km² in 2002 to 163 km² in 2007 (Beijing Municipal Commission of Urban Planning 2007).
12
13 The setback is attributed to weak planning regulation (Yang 2008; Han & Long 2010).
14
15 However, there is a lack of research and a gap in understanding and measuring the economic
16 impacts of greenbelts. In the revision of current greenbelt policy, planners have proposed an
17 alternative configuration that breaks greenbelt into green-wedges and green-grid (Beijing
18 Urban Planning and Design Institute 2007; Beijing Municipal Government 2017). Their
19 economic impacts have not yet been rigorously tested either.
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25 In order to mitigate the overconcentration of business activities and population in Beijing, the
26 national government has launched a Master Plan of Beijing-Tianjin-Hebei Integrated
27 Development in 2015 (Central Political Bureau of China & The State Council 2015). This
28 plan emphasises that regional integration is crucial for tackling the perceived overcrowding in
29 Beijing. Expressways and high-speed railway projects have been proposed to facilitate the
30 redistribution of economic activities and population, but there are few exiting tools to
31 understand and measure the effects of such strategic plans.
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37 In order to include all relevant land use activities and transport flows within the megacity
38 region, both for the present spatial extent and for the expected future expansion, our Greater
39 Beijing Model includes Beijing Municipality, Tianjin Municipality and Hebei Province. The
40 model zoning at the level of local cities and counties allows the effects of strategic
41 greenspace scenarios to be assessed at a level that is consistent with local governance for
42 investment and regulation, as well as for region-wide coordination.
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47 The region is divided into 209 zones according to the existing administrative boundaries and
48 transport links. Beijing Municipality is divided into 130 zones with a detailed road network.
49 Out of the 130 zones, 28 zones at Beijing's urban fringe are selected as *greenbelt zones* for
50 policy test purposes. A *greenbelt zone* may turn into a built-up zone, be preserved as the
51 greenbelt, or a zone with multiple Transit Oriented Development (TOD) nodes. For a zone
52 with TOD nodes, development takes place around each station in relatively high net density,
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3 and both housing and business floorspace are allowed following the Density-Diversity-
4 Design principle (Ewing & Cervero 2010). These areas are expected to yield low vehicle
5 ownership, high transit and walking mode shares on work trips and short drive times to work
6 (Cervero 2015; Ewing & Cervero 2010; Cao & Chatman 2016; Ewing & Cervero 2017).
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10 We further classify the 130 zones in Beijing Municipality into 6 categories: 1) the central city,
11 2) the inner city, 3) the greenbelt zones, 4) the new towns, 5) the far suburb and 6) the
12 ecological protection area (EPA).
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17 [INSERT FIGURE 2 HERE]
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22 *Greenspace scenarios*

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24 Based on the existing plans and the historical development trends, we classify three
25 greenspace configurations from 2010 to 2030: 1) Beijing's past expansion has pointed to the
26 concentric growth as the default *Trend* development scenario, which means no specific
27 greenspace intervention will be implemented. 2) Despite the fragmented remaining
28 greenspaces, there are appeals for no more development in the designated second greenbelt
29 (Beijing Municipal Government 2008; Beijing Municipal Commission of Urban Planning
30 2012). Therefore, the *Greenbelt* is the second scenario. 3) As the mixed greenspace
31 configuration has been proposed in the latest masterplan, we test it as the third scenario,
32 called *Green-grid*. In this scenario, parts of the greenbelt will be gradually built-up, and the
33 ring-shaped greenbelt will evolve to wedges then to a grid over time. The selected built-up
34 areas are those with metro or train services. Such built-up areas are TOD nodes. Figure 3 is a
35 diagram that illustrates the three scenarios.
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47 [INSERT FIGURE 3 HERE]
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51 The three scenarios are based on the same projections of regional macroeconomic and
52 demographic growth. That is to say, they share the same overall assumptions of total number
53 of population, same regional floorspace stock, and same future road and metro networks as
54 set in the governments' development and infrastructure plan. Metro capacity and fare stay the
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3 same as base year across scenarios, because the service frequency is already very high and
4 the fare is very low. The scenario variations are represented at 1) Where the floorspace
5 growth takes place. 2) How close people live to the transport network in the *greenbelt zones*.
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8 Regarding the first variation, the total floorspace constraints remain the same across scenarios.
9
10 This makes it possible for a consistent comparison between the scenarios for the level of
11 floorspace rents. Zonal floorspace constraints are defined endogenously in the model. The
12 floorspace growth is divided into natural growth and added growth. Natural growth is the
13 spontaneous expansion through extension of the existing buildings or infilling development
14 in built-up areas. It is distributed proportionally to the existing stock size, unless defined as
15 zero in greenbelt zones (see Table 1). Added growth is designed to reflect the land allocation
16 and policy interventions. It is distributed endogenously in the Recursive Dynamic Model
17 according to price levels in the previous decade (See Equation 9 and 10 for the calculation of
18 floorspace supply). We follow the assumption from Jin et al. (2017) and define that natural
19 growth accounts for 50% of the projected total growth. This ratio can be modified by the
20 modeller.
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28 Regarding the second variation, the transport proximity is defined in a case-by-case manner
29 only in greenbelt zones according to the scenario. Access links are built from the zonal
30 centroid to each metro station and major road junction to represent the transport proximity.
31 The average access length is calculated using a conceptual circular city model (Holroyd 1966)
32 and validated through Beijing's data (Ma 2017).
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39 [INSERT TABLE 1 HERE]
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45 *Model calibration and specification for forecasts*

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47 A well-calibrated base year is fundamental for the accuracy of future predictions. The
48 predictive capability of LUTI models is assessed through whether a model can reproduce the
49 current (or historical) situation as represented by the data on that situation (Wilson 1998).
50 The Greater Beijing model is established based on cross-sectional data for three decades,
51 namely 1990, 2000, 2010. The model is calibrated for year 2010, and validated through
52 reproducing year 1990 and 2000. The multiple cross-section validation ensures that model is
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3 well structured and calibrated for predicting medium to long term trends (Wan & Jin 2017).
4 Parameters and data inputs for calibration are reported in Supplementary Material 2.
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6 We then run the model from year 2010 to year 2030¹, based on the following segmentations:
7 3 social-economic groups (high, medium, low) segmented according to their income levels
8 and jobs; 5 travel modes (car, bus, walk, cycle, metro/rail); 4 travel purposes (commuting,
9 education, business, other) in line with the transport survey in Beijing.
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13 14 *Results*

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17 *Aggregate modelling results on Beijing municipal level.* The aggregate level modelling
18 results show that greenspace interventions will have a wider impact beyond Beijing
19 Municipality onto the entire region. Compared to the Trend scenario, both Greenbelt and
20 Green-grid stimulate a relocation of population and jobs from Beijing to its surrounding areas.
21 The magnitude of the relocation is more obvious with the implementation of the strict
22 greenbelt. The Greenbelt scenario has the least housing provision. The shortage of floorspace
23 pushes rent up by 7% for housing and 3% for business floorspace, despite the shrinking
24 demands due to the decrease of population and employment in Beijing.
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40 *Localised results.* Compared to Trend, the greenbelt zones lose more than half of the
41 residents and jobs in the Greenbelt scenario (see Figure 4). People move from the greenbelt to
42 the inner city, instead of new towns in the far suburb. While people concentrate in the centre,
43 there is no added employment. Jobs are pushed further from the greenbelt to the wider south-
44 east transport corridor towards Tianjin.
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53 ¹ In order to highlight the difference between the traditional static model and our recursive
54 model, we did both a static run and a recursive run from 2010 to 2030. Supplementary
55 Material 3 provides a comparison between the two modelling methods.
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3 The impacts of Green-grid are relatively local within the urban fringe. With the sheer drop of
4 the number of residents in the preserved greenbelt zones, TOD nodes become popular.
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6 Number of jobs also increases in TOD nodes to achieve work-home balance.
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17 Figure 5 shows the variations in housing floorspace supply and rent. Under the greenbelt
18 restriction, the floorspace supply in the greenbelt is remarkably low. Meanwhile, because less
19 people live in the greenbelt, the shrinking demand brings down housing rent by about 10%.
20 Housing rent in the rest of Beijing goes up in general and the rent in the city centre increases
21 by 13%. Note that the amenity value of the greenbelt is not modelled explicitly; instead, it is
22 included in the residual attractiveness E_{fij} (see Supplementary Material 1, Equation 2). The
23 residuals are empirically calibrated for 2010, so any potential increase of amenity value from
24 2010 to 2030 may be underestimated, and thus the magnitude of rent decrease in greenbelt
25 zones may be overestimated. In Green-grid, the TOD nodes become popular primarily
26 because of the sufficient floorspace supply. Most of the nodes see a more than 50% increase
27 in housing supply and rent increases accordingly because of the rising demand.
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38 [INSERT FIGURE 5 HERE]
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43 Table 3 reports the transport modelling results. On the regional level, a reduction of VMT can
44 be observed in the Green-grid scenario. For Beijing Municipality and its urban fringe, mode
45 choice shifts from car to non-vehicle and public transport can also be observed. The overall
46 mode choice shift is due to the work-home balance in TOD nodes. As people work locally,
47 intra-zonal commuting is promoted where car is uneconomic: intra-zonal journeys are in
48 general shorter than inter-zonal journeys, so off-network travel time and parking fee (p_{jm}^t in
49 Equation 8) account for a larger proportion in the generalised travel costs in car journeys,
50 which reduce the advantages of cars compared to other modes. Additionally, for TOD nodes,
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3 development takes place around stations so that the access time to public transport is shorter,
4 which promotes metro mode share.
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13 Figure 6 reports variations in consumption utility among scenarios. Utility is determined by
14 two factors: how much floorspace a household can afford to rent and how many goods they
15 can buy. Under the Trend scenario, due to the high rent in Beijing, the utility level in Beijing
16 (6.40) is generally lower than its surrounding areas (6.75 regional average), and the inner city
17 is even lower due to the high price level. The Greenbelt scenario fails to improve the
18 consumption utility for most zones, as the average utility drops to 6.38. The designated
19 greenbelt area is an exception. With the decrease of population and the drop in rent, the
20 greenbelt turns into an affordable area at the cost of making the rest of Beijing more
21 expensive. In Green-grid, consumption utility witnesses an overall increase in Beijing to 6.42,
22 with the exceptions of a limited number of TOD nodes and suburban zones. Under Green-
23 grid, the total residents decrease by 2% in Beijing while housing supply remains the same.
24 The shrinking demand brings rent down by 1%. Moreover, the average commuting distance
25 decreases from 13.6 km in Trend to 13.1 km, mainly because more people work locally, and
26 the access distance to stations are shorter.
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37 When we convert the utility into monetary terms by Equation 12, the drop of utility in
38 Greenbelt equals a loss of \$349 per employed resident per year, which equals \$3.3 billion for
39 the whole municipality. This drop accounts for 1.56% total household disposable income. In
40 Green-grid, the increase of utility equals \$385 per employed resident, which means Beijing
41 gains \$3.6 billion. This increase accounts for 1.72% total household disposable income.
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47 [INSERT FIGURE 6 HERE]
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51 52 **Discussions and conclusions** 53

54 In the context of the policy goal for regional integration, the modelling results highlight the
55 significant geographic variations of impacts. A strict control of the greenbelt will relocate 6%
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3 of the population from Beijing to Tianjin and Hebei, which at the face value may be
4 considered a positive contribution to relieving overcrowding in Beijing. However, on closer
5 look, under the current inter-city transport plan, the greenbelt will concentrate more
6 employed residents (0.55 million) in Beijing's city centre. In this sense, the strict greenbelt
7 may not relieve overcrowding where the growth pressures are the highest, and could even
8 exacerbate it.
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13 The model results help to pinpoint where the growth pressures are highest under a given
14 scenario. For example, the Beisanxian County (refer to Figure 2) stands out as facing high
15 pressures for housing development and employment growth under Trend and Greenbelt
16 scenarios. Such findings could prompt planners to further investigate the potentials of
17 transport investment to connect Beijing and Beisanxian to promote intercity-commuting and
18 relieve overcrowding.
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23 From a local perspective, a greenbelt is unlikely to be the highest performing intervention for
24 Beijing's economic wellbeing. The negative effects of the greenbelt, such as less housing
25 supply (11% lower than Trend), higher housing rent (7% higher than Trend), lower
26 productivity (3% lower than Trend), and a decrease in consumption utility (0.3% lower than
27 Trend) would weaken the leading role of Beijing in the city region. Although Beijing's
28 greenbelts have been extensively studied in terms of environmental benefits (Yang & Zhou
29 2007; Tan 2008; Gan 2012; Han & Long 2010), the findings here indicate that their economic
30 impacts should be studied in more depth. In future strategic greenspace design, the economic
31 as well as environmental effects should be considered. Also, it might be difficult to achieve
32 both environmental and economic benefits through a single greenbelt policy. The possibility
33 of combining greenbelts with other policies, for example congestion tolls (Anas & Rhee 2006)
34 could be considered and tested using tools like this model.
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43 The green-grid, which stands for a flexible and mixed greenspace configuration, would
44 appear to be an option that better balances economic efficiency and environmental benefits in
45 terms of reducing car usage. Building around metro/rail stations at a relatively high density
46 benefits local residents, as consumption utility sees an overall increase. Compared to Trend,
47 journeys on public transport increase by 28% and active travel by 57%, while those using
48 cars are down by a third at the urban fringe. Such findings are in line with the previous
49 studies (Cervero 2015; Ewing & Cervero 2010; Cao & Chatman 2016; Ewing & Cervero
50 2017). However, our model also finds that housing and business floorspace rents increase in
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3 TOD nodes. This indicates that the design of TOD nodes needs to account for such effects
4 and might need to combine other policies to secure floorspace supply.
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7 As the land use demand changes rapidly in Beijing, it appears to be beneficial for policy
8 makers to periodically review where should be relaxed in the designated greenbelt, and to
9 allow patches of land to be developed in certain areas. Such sites need to be carefully selected
10 around metro stations to accommodate the forthcoming growth. More generally, a flexible
11 design of greenspace configurations and a careful siting of new development in the
12 designated greenbelt area could bring potential benefits to residents' wellbeing.
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17 This model provides a systematic analytical platform for predicting, comparing and analysing
18 the performance of alternative greenspace configurations over time. Under rapid urban
19 transformation, large scale greenspace policies need to be reviewed constantly using tools
20 such as that presented in this research. On the one hand, urban greenspaces need to be
21 implemented as firm designations in order to enhance the environment quality. On the other
22 hand, under fast growing conditions, the population sizes and land use needs may radically
23 change from assumptions previously made. It can be beneficial to modify the existing
24 greenspace configurations in line with the new contexts of urban development. This is a
25 difficult call for decision makers, and the new model will help to shed light on the potential
26 economic costs and benefits between the alternative propositions.
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34 This paper presents a strategic study on examining the economic impacts of greenspaces. The
35 model works on aggregated zones, which makes measuring the sub-zonal level proximity to
36 greenspaces difficult. Also, there is no explicit agency of government or developer, so it is
37 difficult to accurately test the impacts of greenspaces in combination of other policies related
38 to such agencies. Moreover, the model does not develop a platform for comparing the
39 economic costs to the environmental benefits of greenspaces. Instead, it intends to emphasise
40 the importance of assessing economic impacts in decision making process. In the future, the
41 spatial granularity of the model needs be improved and more agencies could be added when
42 data are available to improve the model's realism. The model could interface with micro
43 simulation models to improve the representation of consumer and producer's behaviour. The
44 model can also interface with other models that are specialised in quantifying environmental
45 impacts to generate a more complete picture to assist decision making.
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Table 1 Locations of floorspace development

Scenarios	Locations of floorspace development									Proximity to transport network	
	Centre	Near Suburb	Greenbelt zones	(TOD nodes)	New Towns	Far Suburb	EPA	Road access link length	Station access link length		
1 <i>Trend</i>	×	√	√	N/A	√	√	×	93% r	86% r		
2 <i>Greenbelt</i>	×	√	0	N/A	√	√	×	100% r	114% r		
3 <i>Green-grid</i>	×	√	0	√+	√	√	×	Same as scenario 2 except for TOD nodes, where 96% r 58% r			

Note

- √ denotes both natural growth and added growth are allowed
- ×
- 0 denotes no growth is allowed
- √+ denotes both natural growth and added growth are allowed; meanwhile, added growth is promoted
- r is the zonal radius, which is the arithmetic average distance from the geometrical centroid to all the perimeter vertices.

Model calibration and specification for forecasts

Table 2 Aggregate modelling results on Beijing municipal level

	1 <i>Trend</i>	2 <i>Greenbelt*</i>	3 <i>Green-grid*</i>
Employed residents (Thousand people)	18887	-6%	-2%
Employed workers (Thousand people)	18980	-6%	-2%
Housing floorspace supply (million m²)	1169	-11%	0%
Housing floorspace within the originally designated greenbelt zones in 2030 (million m²)	330	-42%	-1%
Business floorspace supply (million m²)	461	-4%	0%
Business floorspace within the originally designated greenbelt zones in 2030 (million m²)	107	-41%	9%
Average housing rent (\$/m²/year)	194	7%	-1%
Average business floorspace rent (\$/m²/year)	81	3%	-2%
Total production in quantity of composite goods (millions)	5687	-3%	-2%

* Percentage of change to Trend

Table 3 Main transport modelling results

	<i>1 Trend</i>	<i>2 Greenbelt</i>	<i>3 Green-grid</i>
Vehicle miles travelled in Beijing-Tianjin-Hebei Region			
Passenger miles travelled per person per year	6994	6989	6893
Vehicle miles travelled per person per year	3282	3247	3148
Commuting trips in Beijing			
Average commuting distance	13.6	13.3	13.1
Trips by car (thousand trips)	9108 (58%)	8443 (57%)	8097 (52%)
Trips by non-vehicle modes (thousand trips)	1864 (12%)	1795 (12%)	2126 (14%)
Trips by public transport (thousand trips)	4753 (30%)	4546 (31%)	5191 (34%)
Commuting trips in greenbelt zones			
Trips by car (thousand trips)	2552 (60%)	1365 (62%)	1686 (42%)
Trips by non-vehicle modes (thousand trips)	489 (12%)	221 (10%)	766 (19%)
Trips by public transport (thousand trips)	1204 (28%)	631(28%)	1541(39%)

Figure 1 Modelling structure

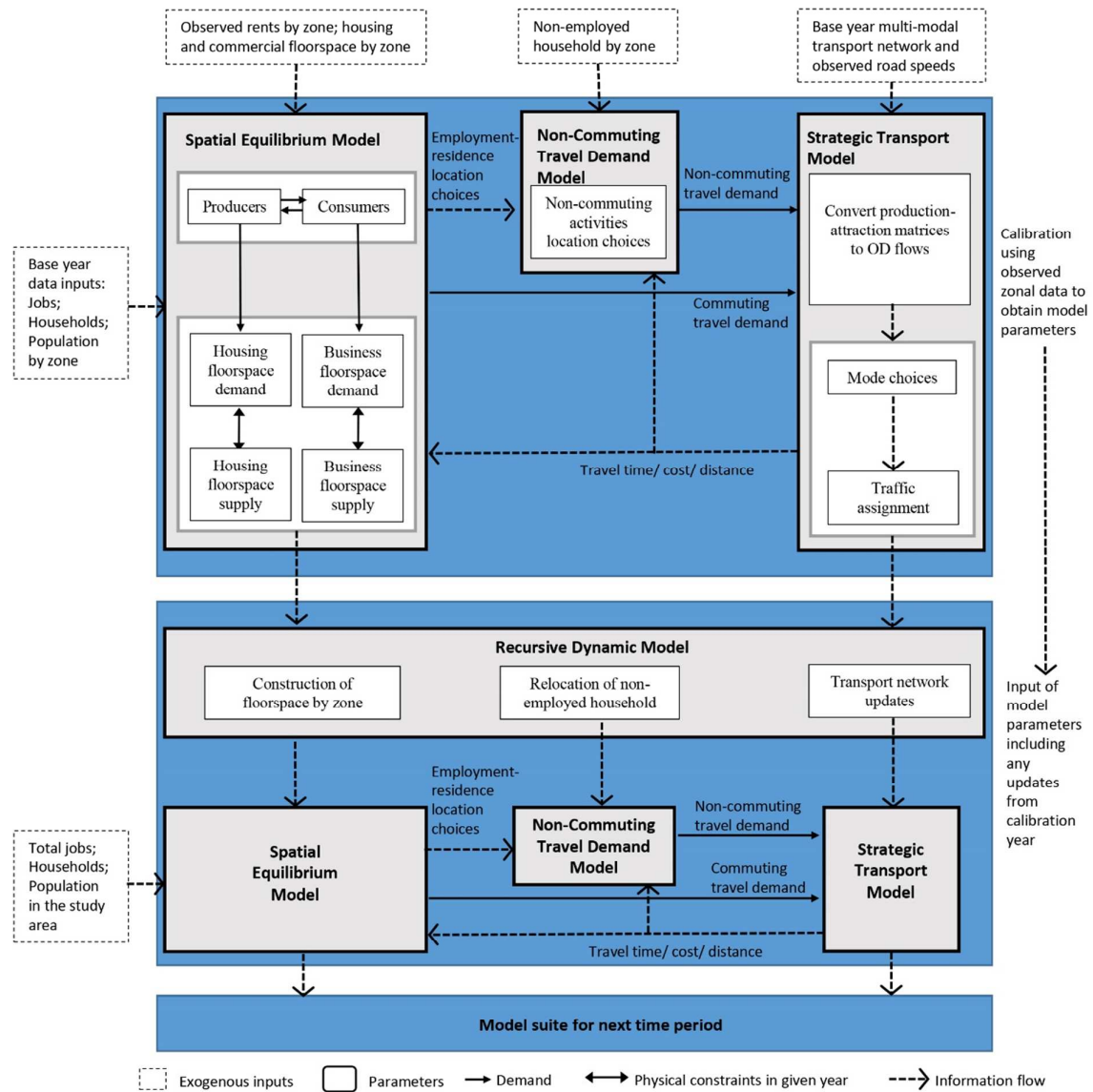
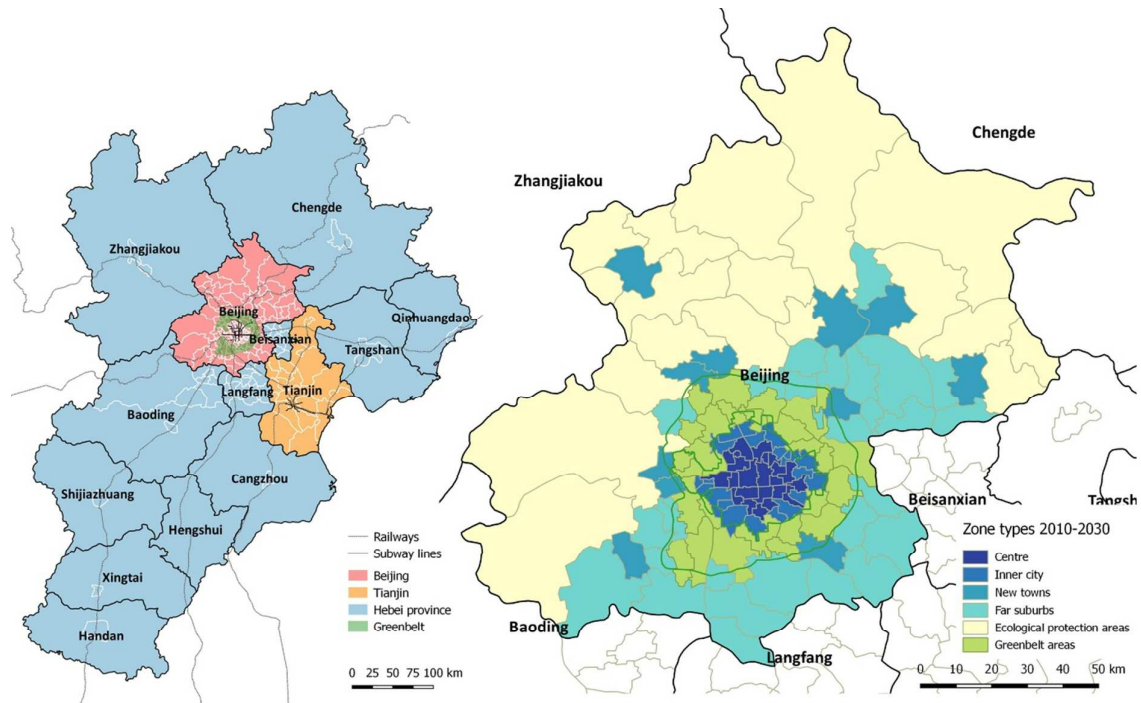


Figure 2 Geographical extent (left) and zone categories in Beijing (right)



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Figure 3 Scenarios of greenspace configurations

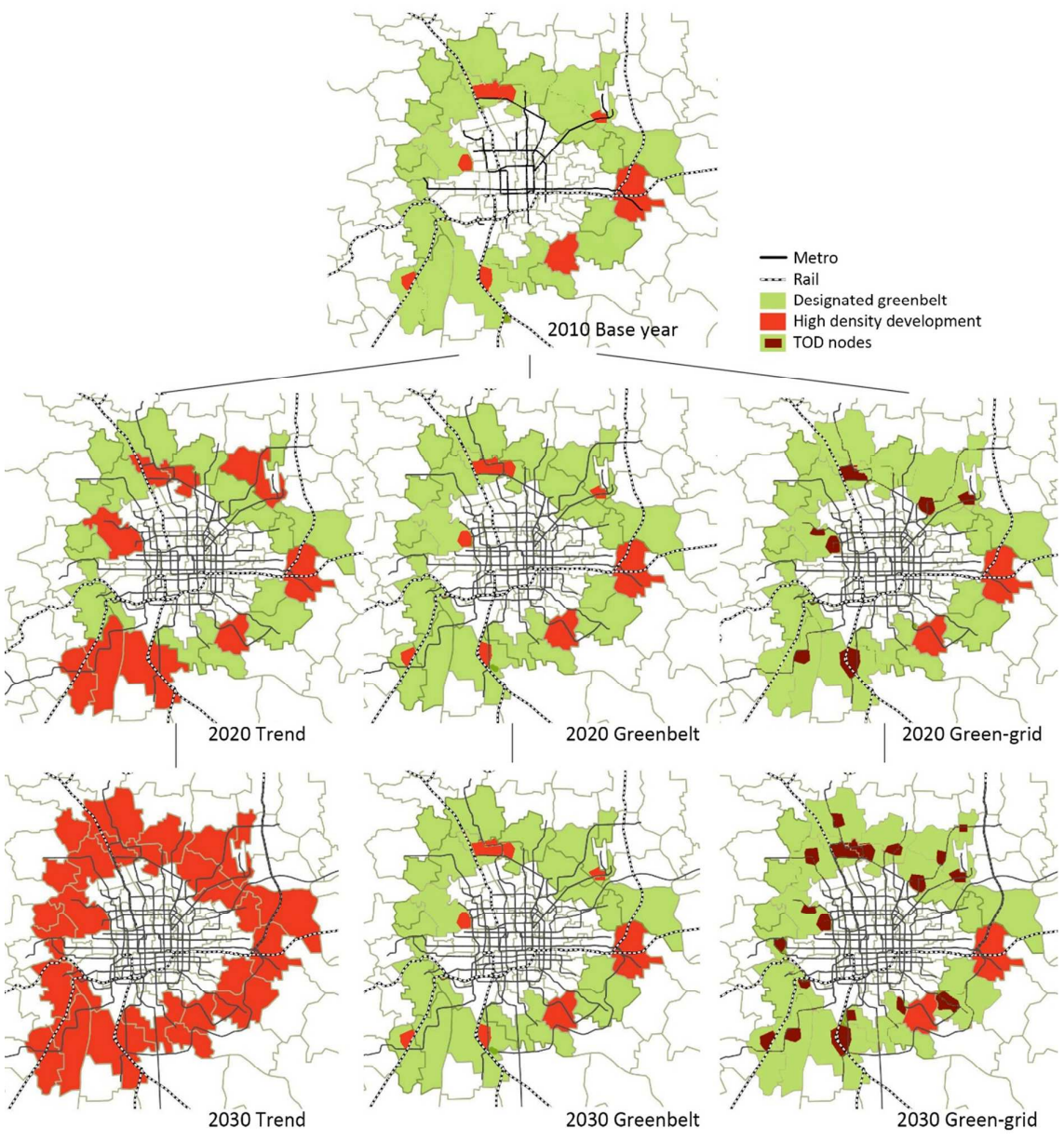


Figure 4 Distribution of employed residents and workers in Trend, and the changes in Greenbelt/Green-grid compared to Trend

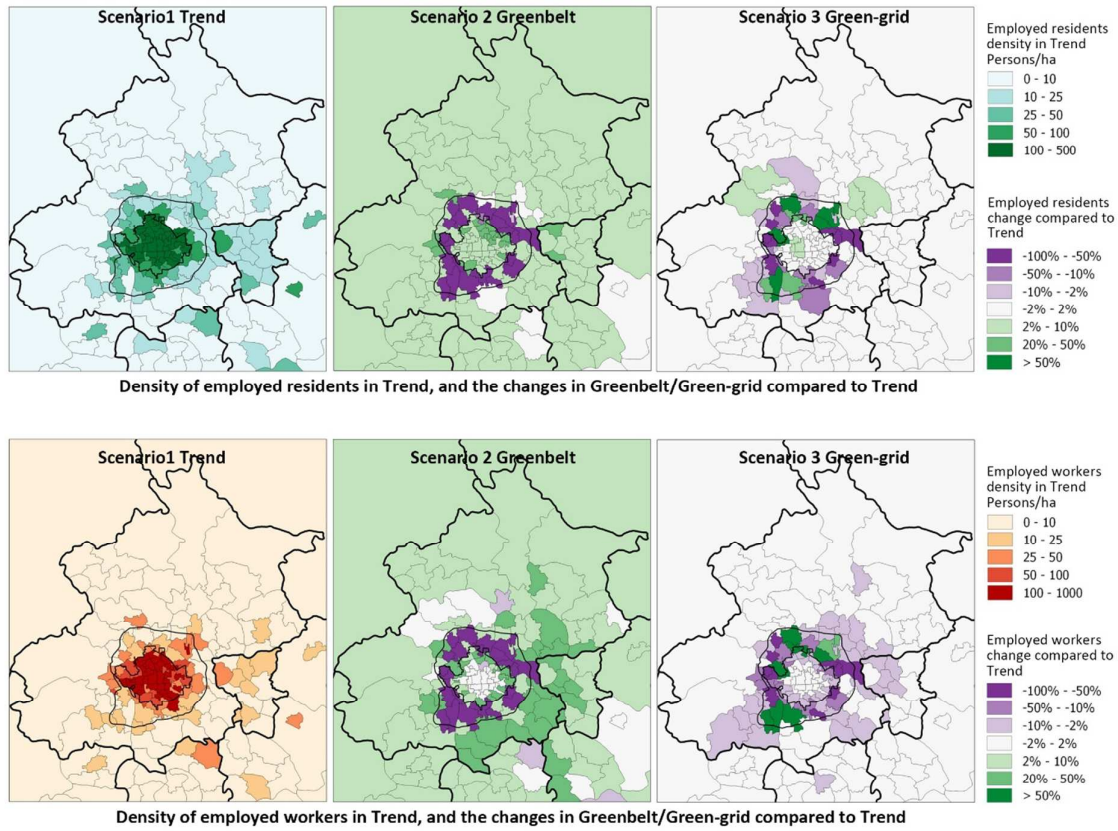


Figure 5 Housing floorspace density and rent in Trend, and the changes in Greenbelt/Green-grid compared to Trend

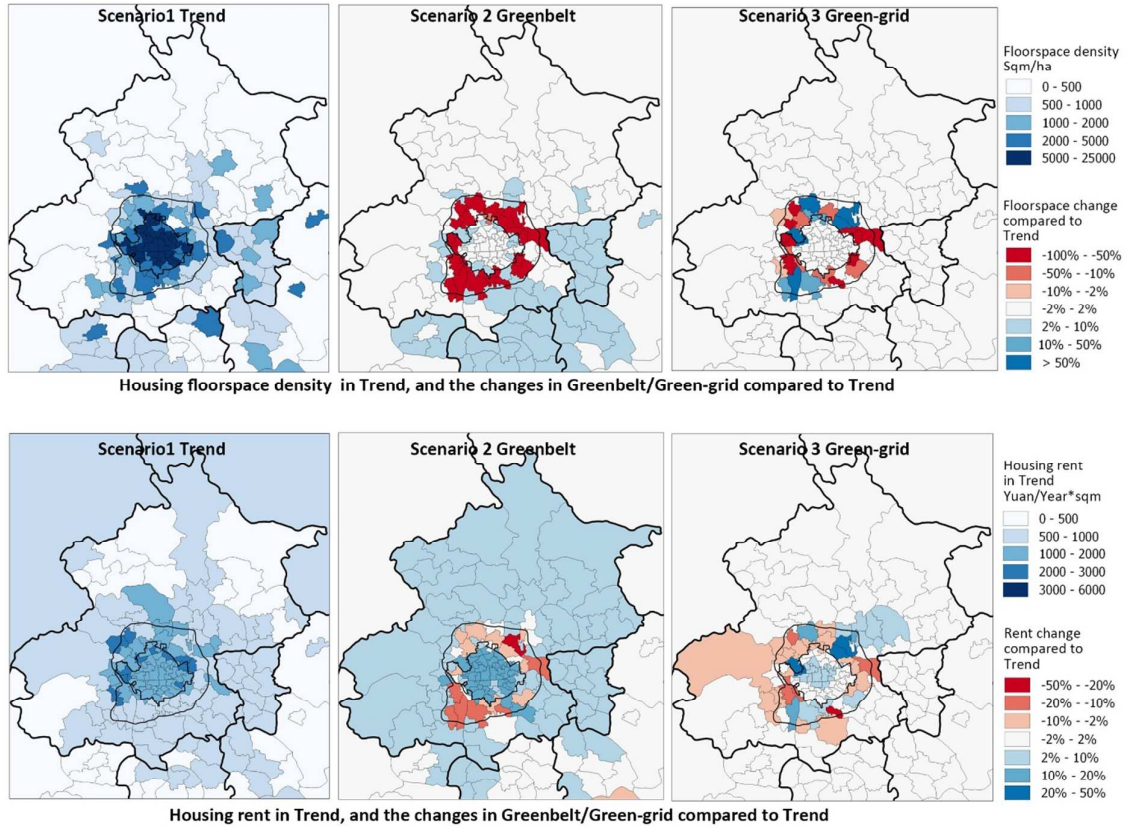
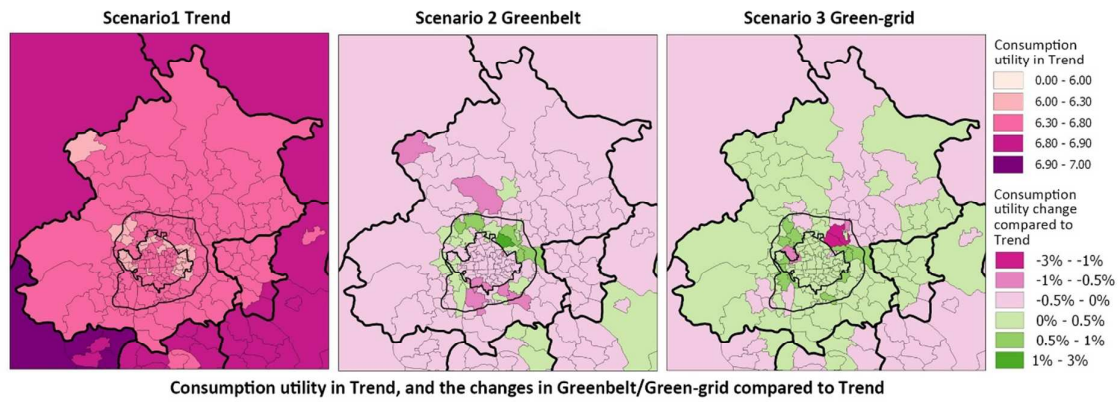


Figure 6 Utility level in Trend, and the changes in Greenbelt/Green-grid compared to Trend



Consumption utility in Trend, and the changes in Greenbelt/Green-grid compared to Trend

Supplementary material 1: key equations

Key equations are summarised following the order of 4 sub-models:

Spatial Equilibrium Model

Following the tradition of Anas and Liu (2007) and Jin, Echenique and Hargreaves (2013), the producers and consumers' behaviour follows a parsimonious design. It 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. 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.

The production function follows a hybrid Cobb-Douglas CES form. Producers can choose any zone to locate. The output X_{rj} of a certain industrial type r in a zone j is:

$$X_{rj} = E_{rj} A_{rj} (K_r)^{\nu_r} \left(\sum_f \kappa_{rfj} L_{rfj}^{\theta_r} \right)^{\frac{\delta_r}{\theta_r}} \left(\sum_k \mathcal{H}_{rkj} B_{rkj}^{\zeta_r} \right)^{\frac{\mu_r}{\zeta_r}} \prod_s (Y_{rsj})^{\gamma_{rs}} \quad [\text{Equation 1}]$$

In this hybrid Cobb-Douglas CES function, primary inputs are the capital K_r , labour force L_{fj} , business floorspace B_{kj} and intermediate inputs Y_{rsj} . The subscripts f , k and s stand for the types of labour force, business floorspace and goods respectively. E_{rj} is scale parameter. A_{rj} is the economic mass parameter which represents the urban agglomeration effects. This function is rendered constant returns by $\nu_r + \delta_r + \mu_r + \sum_s \gamma_{rs} = 1$. The elasticity of substitution between any two types of labour forces and building floorspace are $\frac{1}{1-\theta_r}$ and $\frac{1}{1-\zeta_r}$. κ_{rfj} and \mathcal{H}_{rkj} are input-specific constants for choosing between types of labour forces and business floorspace.

Consumers are also categorised into f types by their socio-economic status. They can work in any zone, live in any zone and purchase goods in any zone, subject to the maximised individual utility. Each consumer decides where to be employed and where to live based on a combined utility. Following the random utility framework (McFadden 1974), an individual in the population has an employment-resident location utility function:

$$U_{fij} = V_{fij} - d_{fij} + E_{fij} + e_{fij} \quad [\text{Equation 2}]$$

Where V_{fij} is the consumption utility of living in zone i while working in zone j , which is non-stochastic and reflects the representative taste of the population, d_{fij} is the travel disutility from i to j , E_{fij} is the residual attractiveness term for a zone pair ij which is calibrated empirically. It represents the zonal characteristics that are not counted in consumption utility, for example the amenity value of greenspaces. The e_{fij} is stochastic and reflects the idiosyncrasies of the population. The non-stochastic consumption utility V_{fij} consists of three parts: the quantity of retail goods and service a consumer buys, the quantity of floorspace he/she rents, and the time he/she contributes to work or leisure. An individual consumption utility of a type f consumer living in zone i , working in zone j and shopping in any zone z is written as:

$$V_{fij} = \alpha_f \ln \left(\sum_r \left(\sum_z Z_{rz|fij} \right)^{\eta_f} \right)^{\frac{1}{\eta_f}} + \beta_f \ln \left(\sum_k \iota_{kfi} (b_{kfi})^{\sigma_f} \right)^{\frac{1}{\sigma_f}} + \gamma_f \ln l_{fij} \quad [\text{Equation 3}]$$

$\alpha_f, \beta_f, \gamma_f$ are the shares of disposable income spent on the retail goods and service $Z_{rz|fij}$, housing floorspace b_{fij} , and annual leisure time l_{fij} and they follow the Cobb-Douglas constant returns by defining $\alpha_f + \beta_f + \gamma_f = 1$. The subscripts r and k stand for the type of goods and the type of housing floorspace respectively. ι_{kfi} is the input-specific constant for choosing the housing type k for type f consumer in zone i . $\frac{1}{1-\eta_f}$ and $\frac{1}{1-\sigma_f}$ are respectively the elasticities of substitution between any two retail goods and any two types of housing.

For a given employment-residence location ij , by assuming the stochastic term e_{fij} follows Gumbel distribution, the probability for living in zone i and working in zone j is represented in a logit form:

$$P_{fij} = \frac{S_i \exp(\lambda_f (V_{fij} - d_{fij} + E_{fij}))}{\sum_i S_i \exp(\lambda_f (V_{fij} - d_{fij} + E_{fij}))} \quad [\text{Equation 4}]$$

S_i is a size parameter that corrects for the bias introduced by the uneven sizes of zones in the model. λ_f is the concentration parameter for employment-residence location choice.

Non-Commuting Travel Demand Model

Given the zonal numbers of employed residents and workers, the Non-Commuting Travel Demand model generates non-employed individual persons within each type of household into different categories c following a social accounting matrix. Then it generates non-commuting travel demands in line with the categories. Such categories are based on the non-commuting travel demand segments in survey. The travel demand generation also follows a social accounting matrix form.

$$T_i^t = \sum_c a^{tc} Y_i^c \quad [\text{Equation 5}]$$

T_i^t is the total number of non-commuting trade type t generated at the origin zone i . Y_i^c is the number of individuals of category c in zone i , and a^{tc} is the trade generation matrix. Trade types t are classified by travel purpose and within each purpose, by socio-economic group f .

As the trades are generated from the origins, another discrete choice model is used to select the destinations of non-commuting trades.

$$T_{ij}^t = T_i^t \frac{S_j^t e^{-\lambda^t (d_{ij}^t + w_j^t)}}{\sum_j S_j^t e^{-\lambda^t (d_{ij}^t + w_j^t)}} \quad [\text{Equation 6}]$$

T_{ij}^t is the trade flow of non-commuting activities t from zone i to zone j . T_i^t is the total trip generated from zone i . S_j^t is the size parameter of type t activities in zone j . d_{ij}^t is the travel disutility of type t activities from zone i to zone j . w_j^t is a constant, which varies according to the types of activities and zones.

Strategic Transport Model

Given the predicted travel demands from the Spatial Equilibrium Model and Non-Commuting Travel Demand Model, the Strategic Transport Model distributes trips among different travel modes on each link, given a certain network supply. Given the total trip flows

F_{ij}^t (converted from trade T_{ij}^t through trip generation matrix) for a specific OD pair from i to j , the model distributes trips into modes based on a logit model:

$$F_{ijm}^t = F_{ij}^t \frac{e^{-\lambda_m^t D_{ijm}^t}}{\sum_m e^{-\lambda_m^t D_{ijm}^t}} \quad [\text{Equation 7}]$$

$$D_{ijm}^t = \phi^t c_{ijm}^t + t_{ijm}^t + p_{jm}^t + \Omega_m^t \quad [\text{Equation 8}]$$

Where F_{ijm}^t is the trips of type t from zone i to zone j on mode m . The modal disutility D_{ijm}^t consists of four elements: out-of-pocket travel cost c_{ijm}^t converted into time units through the marginal utility of money ϕ^t , travel time t_{ijm}^t , destination disutility (such as off-network travel time and parking fee) p_{jm}^t , and modal specific constant Ω_m^t (Jin et al. 2002). λ_m^t is the concentration parameter for inter-zonal mode choice. Travel disutility d_{ij} (in [Equation 2] and [Equation 6]) is the log-sum disutility of D_{ijm} over all possible modes.

The cross-sectional model requires the following standard assumptions, given travel disutility D_{ijm}^t , subject to the zonal floorspace stock constraints by type B_{rkj} and b_{kfi} : 1) All consumers maximise utility subject to the housing floorspace, money and time constraints. 2) All producers minimise cost subject to the input factors, which are the floorspace and labour provision. 3) A zero profit condition is set for producers in an open competitive market. The market is zero excess demands in floorspace market, labour market and product market. In labour market, total working hours demand equals total non-leisure hours minus travel time. In product market, total goods and services produced equals total goods and service consumed by consumers.

Recursive Dynamic Model

After a cross-sectional simulation has finished at the first time horizon, the solved prices and quantities will serve as the starting point for the prediction of the next time horizon. The floorspace stocks will respond to urban change over two time horizons, and this is modelled in the Recursive Dynamic Model. The total floorspace stock is user-defined, because this is likely to be the most appropriate in order to reflect policy targets. On a zonal level, Recursive Dynamic Model distributes the total floorspace stock, subject to the spatial pattern from the equilibrium status in the last decade and the background policy trend. The zonal floorspace for a certain type is described in the equation below:

$$B_{ki}^{T+1} = B_{ki}^T + nB_k^{T \rightarrow T+1} \frac{B_{ki}^T}{\sum_i B_{ki}^T} + (1 - n)B_k^{T \rightarrow T+1} \frac{\exp(\lambda_b V_{ki})}{\sum_i \exp(\lambda_b V_{ki})} \quad [\text{Equation 9}]$$

B_{ki}^T is the zonal floorspace stock at zone i for time T . B_{ki}^{T+1} is the zonal floorspace stock at zone i for the next time section $T+1$. $B_k^{T \rightarrow T+1}$ is the total regional stock change of floorspace from time T to $T+1$ defined exogenously. The added regional stock $B_k^{T \rightarrow T+1}$ is split into two parts: natural growth $nB_k^{T \rightarrow T+1} \frac{B_{ki}^T}{\sum_i B_{ki}^T}$ and added growth $(1 - n)B_k^{T \rightarrow T+1} \frac{\exp(\lambda_b V_{ki})}{\sum_i \exp(\lambda_b V_{ki})}$. n is a user-specified portion of natural growth. The zonal natural growth is proportional to the existing stock size. The zonal added growth distribution follows a logit model with a concentration parameter λ_b . V_{ki} is a non-stochastic location-based utility.

$$V_{ki} = \beta_1 \ln \sum_k B_{ki}^T + \beta_2 \frac{\bar{R}_{ki}^T}{\bar{R}_D^T} + \beta_3 \mathcal{D}_{ki}^T + \beta_4 M_{ki}^T + \beta_5 \mathfrak{I}_{ki} + E_D \quad [\text{Equation 10}]$$

Variables in the equation are respectively the existing zonal stock size $\sum_k B_{ki}^T$, average rent over provincial average rent $\frac{\bar{R}_{ki}^T}{\bar{R}_D^T}$, zonal floorspace density \mathcal{D}_{ki}^T , economic mass M_{ki}^T , policy dummy variable \mathfrak{I}_{ki} and provincial residual term E_D .

Major transport constructions tend to be the most durable and irreversible urban changes. Therefore, the most appropriate way to update the transport supply, namely the network in the model, is to add or demolish infrastructure according to the long term official development plan. Zones at the urban fringe which might be affected by different greenspace configurations will have a variable A_l to represent the proximity from the built-up areas to the transport network.

$$A_l = a_l r \quad [\text{Equation 11}]$$

Where A_l is the access link length from zonal centroids to the road access nodes or stations for built-form l . r is the radius of the zone. a_l is the ratio of access link length to radius for built-form l . a_l is calculated using a generic urban form model (Holroyd 1966). Details of defining and validating A_l can be found in Ma & Jin (Ma & Jin 2016).

Model Assessment

The overall consumer surplus, ΔC , as a household well-being measure may be defined as the change in average household utility divided by the average marginal utility of money.

$$\Delta C = \frac{(\bar{U}_{Alternative} - \bar{U}_{Base})}{\frac{1}{2} \left(\frac{1}{\bar{\Omega}_{Alternative}} + \frac{1}{\bar{\Omega}_{Base}} \right)} \quad [\text{Equation 12}]$$

where \bar{U}_{Base} and $\bar{U}_{Alternative}$ are the average household utilities; $\bar{\Omega}_{Base}$ and $\bar{\Omega}_{Alternative}$ are the average household incomes for the base and alternative scenarios, respectively.

Supplementary material 2: parameters and data inputs for calibration

The following charts list the parameters used in the four sub-models respectively. Sources are given for each group of parameters.

Most of the parameters are from officially published statistical yearbooks, censuses, travel surveys and input-output tables.

Parameters starred with * or ** are calibrated by the authors and are labelled “own calibration” in the charts. Data input for calibration are reported under each individual chart.

In general, there are four groups of calibrated parameters: firstly, by adjusting the concentration parameter λ_f in Equation 4, the differences between the observed and modelled commuting distances and times should be less than 1%. Secondly, by adjusting E_{fij} in Equation 4, the differences between the observed and modelled zonal numbers of population and jobs should be less than 0.1%. Thirdly, by adjusting the concentration parameter λ_m^t by each trip purpose in Equation 7, the differences between the observed and the modelled trip range distributions should be less than 3%. Fourthly, by adjusting modal specific constant Ω_m^t in Equation 8, the differences between the observed and the modelled mode shares should be less than 1%.

There are a few parameters that we do not currently have data to calibrate. In such cases, we have taken values that are proven to be fairly stable in the existing literature on models of this type. Such parameters are mainly concerning the elasticities of substitution among floorspace varieties and labour varieties. These parameters are selected through elasticity tests and based on previous studies (Anas & Rhee 2006; Wan & Jin 2017). With more data published in the future, the parameters could be estimated and modified for Greater Beijing.

Key parameters for the Spatial Equilibrium Model

Parameters	2010 value	Sources
δ_r labour cost share	0.88	Beijing IO table (2010)
μ_r business floorspace cost share	0.12	Beijing IO table (2010)
ζ_r elasticity of substitution for business floorspace varieties	0.90	Anas and Rhee (2006)
θ_r elasticity of substitution for labour varieties	0.75	Beijing-Tianjin-Hebei Model, Wan (2016)
σ_f elasticity of substitution for housing varieties	high: 0.90 mid: 0.90 low: 0.90	Anas and Rhee (2006)
E_j productivity multiplier	1.00	Anas and Rhee (2006)
c_f Cost for delivering a unit of local services as percentage of commuting trip cost	0.10	Anas and Rhee (2006)
α_f utility coefficient for goods & services	high: 0.23 mid: 0.27 low: 0.30 non-emp.: 0.50	Beijing statistical year book 2011
β_f utility coefficient for housing	high: 0.17 mid: 0.26 low: 0.35	Beijing statistical year book 2011
γ_f utility coefficient for leisure time	high: 0.60 mid: 0.47 low: 0.35	Beijing statistical year book 2011
λ_f concentration parameter for residence location choices	high: 3.25 mid: 4.40 low: 4.40	Own calibration using observed commuting statistics*

Parameters	2010 value	Sources
$E_{fj}, E_{fi j}$	varies	Own calibration using
residual attractiveness for	among	observed zonal number of
residence-employment location	commuter	employed residents and
choices	types &	workers **
	across zones	

* Data inputs for calibrating λ_f is the commuting distances and times by socio-economic group from The 4th Beijing Transport Survey Report (Beijing Transportation Research Centre 2012).

** Data inputs for calibrating E_{fij} are the numbers zonal population from Beijing Statistical Yearbooks 2011 and 2016 Population Data (Beijing Bureau of Statistics 2016) available at: <http://www.bjstats.gov.cn/zt/rkjkd> and the datasets Beijing 60 Years 1949-2009 (Beijing Bureau of Statistics & NBS Survey office in Beijing 2009). Zonal jobs are estimated from China Economic Census Yearbook 2008 (National Bureau of Statistics of China 2010), available at: <http://www.stats.gov.cn/tjsj/pcsj/jjpc/2jp/indexch.htm>

Key parameters for the Non-commuting Travel Demand Model

Households type	Children aged 0-5	Children aged 6- 17	Retired	Unemploye d	Total
High	0.067	0.132	0.333	0.129	0.66
Middle	0.068	0.134	0.338	0.132	0.67
Low	0.106	0.210	0.530	0.206	1.05
Non-employed	0.019	0.382	1.580	0.352	2.33

Source: Beijing Statistical Yearbooks 2011 and 2016 population data (Beijing Bureau of Statistics 2016), available at: <http://www.bjstats.gov.cn/zt/rkjkd/>, National Census 2011 (National Bureau of Statistics of China 2016), available at: <http://data.stats.gov.cn/english/easyquery.htm?cn=E0103>

Individual type	School trip	Business trip	Other trip
Employed worker	0	4.35	0*
Children aged 0-5	0	0	0
Children aged 6-17	49.1	0.2	7.9
Retired	0	0.4	58.4
unemployed	0	0.6	53.1
College student	49.1	0.2	7.9
Floating population	0.1	6.1	25.3

Source: The 4th Beijing Transport Survey Report (Beijing Transportation Research Centre 2012).

*We do not have data showing the number of other trips generated by employed workers. We assume the number of such trips in morning peak is few.

Key parameters for the Strategic Transport Model

Flow w	Flow description		Inter- zonal mode choice concentr ation paramet ers λ_m^t	Intra- zonal mode choice concentr ation paramet ers $\lambda_{m B}^t$	Modal specific constants Ω_m^t	Marginal utility of money (minute/cent) ϕ^t
	Trip purpos e	SEG				
1	Commu ting	high	0.06	0.10		0.046877
2		mid				
3		dle	0.07	0.11		0.095804
4		low	0.08	0.12		0.174834
5	Educati on	high	0.06	0.10		0.046877
6		mid				
7		dle	0.07	0.11	varies among	0.095804
8		low	0.08	0.12	SEG groups/trip	0.174834
9	Busines s	high	0.04	0.08	purposes	0.023439
10		mid				
11		dle	0.05	0.09		0.047902
12		low	0.06	0.10		0.087417
13	Other	high	0.06	0.10		0.046877
14		mid				
15		dle	0.07	0.11		0.095804
16		low	0.08	0.12		0.174834
Source			LASER 3.0, Department of Transport & ME&P		Own calibration based on observed mode	Own calibration from income level**

2002 shares and trip
range
distribution*

* Observed mode shares by trip purposes and observed trip range distribution can be found in The 4th Beijing Transport Survey Report (Beijing Transportation Research Centre 2012) and The 5th Beijing Transport Survey Report (Beijing Transportation Research Centre 2016).

** Income level is derived from Beijing Statistical Yearbooks 2011 and 2016 (Beijing Bureau of Statistics 2016) Available at: <http://www.bjstats.gov.cn/zt/rkj/d/>

Key parameters for the Recursive Dynamic Model

Parameters	Values	Sources
Housing floorspace update		
β_1 coefficient for $\ln \sum_k B_{ki}^T$	0.513	Beijing-Tianjin-Hebei Model , Wan (2016)
β_2 coefficient for $\frac{\bar{R}_{kl}^T}{\bar{R}_D^T}$	0.005	
β_3 coefficient for \mathcal{D}_{ki}^T	-0.014	
β_4 coefficient for M_{ki}^T	0.124	
β_5 Coefficient for \mathcal{I}_{ki}	0.965	
E_D residual attractiveness term for BFS growth	Beijing: -0.613 Tianjin: 0.564 Hebei: 0.050	
Business floorspace update		
β_1 coefficient for $\ln \sum_k B_{ki}^T$	0.872	Beijing-Tianjin-Hebei Model, Wan (2016)
β_2	0.009	

Parameters	Values	Sources
coefficient for $\frac{\bar{R}_{kl}^T}{\bar{R}_D^T}$		
β_3	-0.015	
coefficient for \mathcal{D}_{ki}^T		
n	0.875	
portion of natural growth net from the aggregate growth		
λ_b	-1.230	
concentration parameter		
E_D	Beijing: 0.296	
residual attractiveness term	Tianjin: 0.089	
for HS growth	Hebei: -0.385	

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Supplementary material 3: a comparison between a static model and a recursive model for modelling greenspaces

In order to highlight the difference between the traditional static model and our recursive model, we did a parallel test that is to run the model statically. In the static run, zonal floorspace supplies in 2030 are calculated based on the information from the base year 2010. In the recursive run in the last section, zonal floorspace supplies in 2030 are calculated based on the information in 2020, and the 2020 supplies are calculated based on the information in 2010. In other words, the static model jumps from the base year to future years, while the recursive model takes cues from the recent development trend and updates constraints periodically.

Table 1 compares the predicted scales of productivity, floorspace, population, and employment between the static run and the recursive run under the Trend scenario. In the recursive run, the total production is 5% higher in Beijing. This is because the recursive model considers the cumulative urban agglomeration effect over two decades, instead of only the economic size in 2010. The higher productivity in the recursive run leads to higher business floorspace demand and labour demand.

Table 1 Comparison of constrains of static modelling and recursive modelling procedure for Beijing

	Static modelling procedure	Recursive modelling procedure	Difference Recursive vs Static
Total production in quantity of composite goods (millions)	5,422	5,687	5%
Housing floorspace supply (million m²)	1,186	1,169	-1%
Business floorspace supply (million m²)	437	461	5%
Employed residents (Thousand people)	18,123	18,887	4%
Employed workers (Thousand people)	18,158	18,980	5%

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3 For predicting impacts of greenspaces in a city under fast transformation, the recursive
4 modelling procedure appears to have advantages. This is because greenspaces take a long
5 time to shape and the development trend will constantly interact with the implementation of
6 greenspaces over time. Defining modelling constraints and assumptions for future years only
7 based on the information from the base year may not be suitable any more. This requires
8 modellers to adjust the model constraints constantly as a city grows. The recursive model
9 addresses this issue by periodically updating development constraints using the information
10 from the previous decade.
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