A Welfare Evaluation of Green Urban Areas

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A Welfare Evaluation of Green Urban Areas

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Abstract

Urban green areas cover more than 6% of urban land in Europe. This paper quantifies the impact of urban green areas on city structures for more than 300 European cities. It discusses the economic effects of the local amenity produced by green urban areas using an urban economics model with various set of preferences. It estimates those models using data on detailed residential land uses, green urban areas and population density. It finally assesses the economic effects of reducing urban green areas in counterfactual exercises where cities are closed and open to migration and green urban land is converted to residential plots or not. By this strategy, the economic assessment accounts for the general equilibrium effects through endogenous land prices and residential space and location choices. It shows that the gross benefits of urban green areas are substantial. A uniform removal of half of the urban green areas is equivalent to 6-9% reduction of household annual income. However, the conversion of those areas to residential plots brings a net gain of approximately 4%.

Keywords: Urban green areas, urban spatial structure, land use policy, amenities, optimal locations, public facilities, structural estimation

JEL Classification: C61, D61, D62, R14, R53

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1 Introduction

Urban green areas are one of the keys for building resilient and sustainable urban systems. These areas provide valuable local services to urban dwellers such as mitigating air pollution and urban heat islands (Bowler et al. (2010); Manes et al. (2012)), supporting ecological learning (Barthel et al., (2010)) and enhancing human health (White et al. (2013)). They are also an essential block of urban social life as they help to bond urban social ties, providing a place for recreational opportunities and other social benefits (Colding and Barthel (2013), Saldivar-Tanaka and Krasny (2004), White et al. (2013)). It is no doubt that high-quality urban green spaces can bring many relevant services to urban areas, and their locations constitute a crucial component of urban planning in the quest for sustainable cities and communities (Tyvainen et al. (2005)). This fact poses a critical question for city planners: how do the residents value them? Such information is vital to design more desirable residential communities and to thrive by limiting development.

There are three main approaches to evaluating the value of green and open areas. The first approach is the contingent evaluation (CV) method, which asks households directly to specify their willingness to pay (WTP) for the preservation or improvement of specific urban green areas. However, this method depends on hypothetical scenarios, and it does not reflect the actual behaviors of all households. The second approach is the hedonic pricing (HP) method, which reveals the marginal WTP of households through the premium that they give to housing prices through market transactions. The HP method adequately reflects the actual evaluation of households; however, it does not measure the nonmarginal changes for green areas. It also suffers from the ‘Tiebout bias’ (see Kuminoff et al. (2013)), as households can move to other districts in response to a policy change. The third approach is the equilibrium sorting (ES) method, which takes into account the sorting processes of households in the market by simulating a new equilibrium. The gains from the ES method come at a cost, as it is necessary to specify the preference structure and the choice sets available for consumers. Additionally, the housing supply is treated as fixed to allow for simple calibration (Freeman et al. (2014), Kuminoff et al. (2013)). A detailed survey of the literature is reported in Section 2.

In this paper, we utilize a different approach. We first introduce the urban green areas inside an urban land market model and formalize the channel in which the green areas enter households’ decisions and land prices. We employ two different households’ preferences:
Cobb-Douglas and hyperbolic linear utility. The marginal benefit of urban green areas varies across locations within cities according to residential cover, population density and opportunity cost of land at each location. The market equilibrium results in the residential land use at each location across urban areas with a specified level of urban green areas. We then calibrate the equilibrium of residential lands using the data on detailed residential land covers, green urban areas and population density. To control for the potential endogeneity of urban green provision from urban authorities, we employ the green areas in the past as an instrument for the current green areas. We back up the parameters and run counterfactual simulations. To ease the exposition we mainly focus on the clear-cut scenario where urban planners reduce green areas by half. By using this approach, we can account for the new equilibrium in the housing market and households’ choices over housing consumption. We consider both the case of open cities with free migration and closed cities with no migration.

We consider only small and scattered green urban areas in this paper. This is because 95% of urban parks have a surface lower than 0.1 square kilometer, and the average distance between the two parks is lower than 400 meters in our sample of most populated European cities. We estimate residential land use and take the estimated parameters to study the value of green urban areas implied by our theoretical urban land market model. For the parameter estimation, we use the geographical database of the European Environment Agency’s Urban Atlas data, which describes the land use of 305 EU cities with more than 100,000 inhabitants. These data report land use and cover across Europe using harmonized Earth observations (EOs), which are combined with Eurostat Urban Audit statistical data. The data represent a unique source of reliable and comparable European urban planning data. To our best knowledge, this is the first paper that uses the geographical land covers in a theoretical model, empirical estimation and counterfactual quantification of European urban land uses.

Through counterfactual exercises where 50% of urban green areas are removed. Open cities that do not impose restrictions on (e)migration lose more than 6% of their population if those areas are left unused. The total loss for landlords rises to approximately €150 million per city under Cobb-Douglas preferences and to more than €300 million in the case of hyperbolic preferences if green areas are not converted into residential land. The option to convert urban green areas into residential land is however important. This would indeed increase residential surfaces, which would raise the total housing market value by approximately €50 million with Cobb-Douglas preferences and keep a loss of less than €10 million with hyperbolic preferences. The urban economic literature often emphasizes the
economic features of closed cities where tough restrictions on migration are assumed. When residents are stuck to their urban locations, they incur a welfare loss equivalent to between 6% and 9% of their net annual income (this is equivalent to a household’s negative willingness to pay). Such results are robust for preference characteristics. The exercise suggests that urban green areas provide highly valuable amenities to residents. However, when urban green areas give place to new residential covers, they bring a welfare gain that is equivalent to 4.2% of annual household income, suggesting that the land opportunity costs of urban green areas are substantial. Our results confirm Cheshire and Sheppard’s (2002), who find that the net cost of restrictive land use planning is equivalent to 3.9% of households’ income.

Our contributions are twofold. First, we utilize the new set of data, including the geographical land covers, and population grids to estimate the parameters of our theoretical models. We also account for the potential endogeneity in green provision by using the green areas from the past to instrument for the current level of green provision. With these data, we account for the actual residential choices of households in reality instead of hypothetical questions as in the CV method. Second, the use of an urban model together with two different land conversion policies allows us to account for the change in residential land supply and enables us to compute the general equilibrium willingness to pay of households for a significant change in green space provision. This approach, compared with the HP model, addresses the nonmarginal changes in green areas, and it also relaxes the restrictions of fixed housing supply in the sorting equilibrium method. Although our models and counterfactual exercises are readily tractable, they also come with the cost of imposing a specific preference for households. We address this issue partially by considering two types of utility functions: Cobb-Douglas and hyperbolic. We also consider a homogenous households. The extension for household income heterogeneity in this model and calibration would be an interesting direction for future research.

The paper is organized as it follows. Section 2 presents a brief discussion of existing assessment methods of urban green areas. Section 3 presents the baseline theoretical model. Section 4 discusses our data while Section 5 elaborates on the empirical analysis and Section 6 discusses welfare assessment of counterfactual exercises. The last section concludes. Appendices contain additional empirical and robustness information.
2 Literature review

There is a large and growing literature quantifying the value of open and green spaces in urban systems. The first branch of literature is to evaluate green areas through contingent valuation (CV). This approach designs surveys with hypothetical scenarios for environmental goods and asks survey respondents to specify their willingness to pay (WTP) for the preservation or improvement of specific urban green areas. Researchers aggregate those values and estimate the monetary value of this environmental asset. For Europe, Elsasser (1996) and Tyrväinen (2001) use the CV method for the city of Hamburg in Germany and Joensuu and Salo in Finland. They find that the mean WTP was approximately €42 per person per annum in Germany\(^1\) and €60-144 in Finland\(^2\). Schindler et al. (2018) find that the reported willingness to pay for green area access increases with household’s average income. Even though the CV method provides valuable information on how much value each resident places on the usage of green areas, it is based on hypothetical scenarios and does not reflect their actual valuations and behaviors. In comparison, this literature reports lower WTP values than our approach. Nevertheless, the CV method and our approach match with regard to income effects. Indeed, the WTP estimated in our model under Cobb-Douglas preferences increases with income quantiles as it has been estimated by Schindler et al. (2018).

The second approach is hedonic pricing (HP), which evaluates the value of green amenity through its capitalization in the housing market. The premise underlying this approach is that households pay a premium for the green amenity enjoyed in a location. Most studies use housing transaction data, and find that the proximity to parks and open spaces induces an increase in home prices (Bolitzer and Netusil (2000), Geogrehan et al. (1997), Lutzenhiser and Netusil (2001), Smith et al. (2002)). Anderson and West (2006) further reveal that the value of proximity to open spaces is higher in dense and high-income areas. Luttik (2000) find that a pleasant view leads to an increase of 6-12% in house price in the Dutch land market, and Tyrväinen and Miettinen (2000) estimate a 5% increase in home price in Finland. Tyrväinen and Miettinen (2000) find that a one-hectare green area increases the total value of surrounding houses in dense central districts by €11-15 million and single-home less dense areas by €4-5 million. In a competitive land market, this information helps us to infer the marginal willingness to pay for green amenity. Even though this information is undeniably valuable, it does not capture nonmarginal changes in urban green areas. A

\(^1\)in terms of the 1995 price, as cited by Tyrväinen et al. (2005), pg. 102.
\(^2\)in terms of the 2000 price, also per person and per annum
unique departure from this framework is Cheshire and Sheppard (2002). They use hedonic pricing methods to estimate the implicit price for accessible open spaces and then embed them into a monocentric model and calibrate the data for the city of Reading, UK. The use of an urban model allows them to incorporate the general equilibrium effects in their analysis. They estimate that the gross benefit of public open space is £2,424 per household per annum (in 1984 price). However, when they account for the cost of restrictive residential lands, the net loss from planning could be as high as 3.9% of annual household income. By contrast, this paper assesses urban green space of a larger and more international set of cities. When urban planners remove half of the urban green areas, we find a WTP of €970 - 1300 per year per habitant to avoid such a policy. Under reconversion of those lands into residential uses, the net cost of these green areas is estimated at 3.2%-4.2% of annual household income, which is in line with the outcomes from Cheshire and Sheppard (2002).

The third approach is the equilibrium sorting (ES) approach, which seeks to evaluate the large changes in public policies. In contrast to the HP estimation, which assumes that a substantial change in amenity level does not affect household location choice, the ES model seeks to characterize the household’s sorting process in response to a policy change. It is then straightforward to measure both marginal and nonmarginal changes in urban amenity policies by simulating a new sorting equilibrium. Wu and Cho (2003) apply this method to the environmental amenities in Portland, Oregon, and find that a 1.2% increase in the share of parks and open spaces is equivalent to a $100 increase in educational expenditure in household choices for communities. Walsh (2007) uses this sorting method to evaluate the open space protection policy in Wake County, North Carolina, and finds that an open space protection policy in denser areas can lead to a 11.4% increase in house price and approximately 8.14% in less dense areas. Our paper also reports a larger effect in denser areas near the city core and a smaller effect in land price near urban fringes. Klaiber and Paneuf (2010) use a similar approach to estimate household preferences for open space and find that wider divergences between general and partial equilibria with stronger policy changes. However, the ES method is not without constraints. One constraint is that the ES approach is limited in choice sets for housing types due to the difficulties in increasing dimensions for calibration. Hence, most papers use a sorting process through neighborhood instead of household type. This approach must also specify the heterogeneities in preferences

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3 They compare between the current level of 37.9% of residential land to a less restrictive scenario of 42.5% of residential land.

4 For a comprehensive review, see Kuminoff et al. (2013).
(Freeman et al. (2014)). Second, the housing supply is treated as fixed to allow for simple calibration (Freeman et al. (2014), Kuminoff et al. (2013)). In our paper, we allow for land conversion policies, as discussed in the above section, which relaxes the housing supply constraints in a new equilibrium.

3 Theoretical model

The model considers a circular monocentric city. The economy consists of a mass $N$ of individuals living within city boundary and a central business district (CBD) where all households commute to work. We denote $b \in \mathbb{R}_0^+$ as the distance between the CBD and the city border. The population density is defined as the number of individuals in a unit of area at distance $r$ from the CBD and is denoted by the function $n : [0, b] \to \mathbb{R}^+$, which varies across the city.

In this model, we focus on small green urban areas that spread across the city and are closely accessible to the local community around its location. Green urban areas provide quick and frequent access to greenery, quiet, children’s parks, socialization areas, etc. We consider the few blocks in the vicinity of a green urban area as our unit of area or patch and model the urban area in a continuous fashion. In a unit of area at distance $r$ from the CBD, green urban areas offers a service $x : [0, b] \to [0, \overline{x}], \overline{x} \in \mathbb{R}_0^+$, to the local community living in the vicinity. This service brings a level of amenity $a = \alpha x(r)$, although it necessitates the use of a fraction of land $\beta x(r)$ and maintenance costs $\gamma x(r)$. The parameters $\alpha, \beta, \gamma \in \mathbb{R}_0^+$ distinguish the amenity, land use and maintenance factors that affect green urban areas. Hence, the fraction of land used for residential purposes is given by $1 - \beta x$, and the maximum service level $\overline{x}$ is bounded by $1/\beta$. We assume absentee landlords, and the outside opportunity value of land is given by the agricultural land rent $R_A \in \mathbb{R}^+$. For simplicity, we consider that rural areas beyond the city border consist of private properties that do not provide green urban area service for city dwellers (private crop fields, fenced areas, etc.). We denote the land supply at distance $r$ from the CBD by $\ell : [0, b] \to \mathbb{R}^+$ (e.g., $\ell = 2\pi r$ if the city lies in a plain disk). In summary, land at distance $r$ from the CBD includes a surface $\beta x(r)\ell(r)$ of maintained green urban area and a residential area $[1 - \beta x(r)]\ell(r)$, and it hosts $n(r)\ell(r)$ residents who all benefit from the green urban area amenity $\alpha x(r)$.

5Because of proximity of small parks, residents’ travel costs to parks can be neglected here as a first approximation. This contrasts with the literature on the location of scarce public goods, where the travel to public facilities must be considered (see Cremer et al., 1986 and followers).
Individuals consume a quantity $z$ of nonhousing composite goods and a quantity $s$ of residential space, while they benefit from the amenity $a$ of a green urban area. They are endowed with the utility function $U(z, s, a)$, which is assumed to be concave and increasing. We assume that demands for nonhousing composite goods, residential space and amenity are gross substitutes such that $U$ has negative second derivatives and positive cross derivatives. As individuals are homogeneous, they work and earn the same income $w \in \mathbb{R}^+$ in the CBD. Workers incur a total commuting cost $t : [0, b] \to \mathbb{R}^+$ with $t(0) = 0$ and $dt/dr > 0$. The price of composite good $z$ is normalized to 1 without loss of generality. Therefore, the household’s budget constraint is given by $z + Rs + t \leq w$, where $R : [0, b] \to \mathbb{R}^+$ is the land rent function of distance to the CBD. In line with the literature, we assume that the land rent is paid to absentee landlords (Fujita (1989), Fujita and Thisse (2012)). Denote $y \equiv w - t$ as the disposable income net of commuting cost. From this point on and whenever there is no confusion, we dispense the functions $a, \ell, n, s, t, x, z$ and $R$ with reference to distance $r$.

### 3.1 Competitive land market equilibrium

In a competitive land market equilibrium, each land slot is awarded to the highest bidder, and individuals have no incentives to relocate within and outside of a city. Therefore, they reach the same utility level $u$, where the superscript $e$ refers to the equilibrium value. Households bid up to $(w - z - t)/s$ for each unit of residential space. Their bid rent $\psi : [0, b] \to \mathbb{R}^+$ is a function of distance $r$ from the CBD such that

$$\psi = \max_{s, z} \frac{y - z}{s} \quad \text{s.t.} \quad U(z, s, a) \geq u. \quad (1)$$

As individuals compete for land, they increase their bids to make their participation constraint binding and obtain the equilibrium utility level $u$. To solve the problem, we first denote $\tilde{z}(s, a, u)$ as the solution of $U(z, s, a) = u$. As household utility is an increasing and concave function of composite good $z$, it is apparent that $\tilde{z}$ exists and is unique. The bidding

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6We do not formally disentangle the land space used for houses and private gardens. First, our data on urban land cover do not permit to identify each separate item. Second, the empirical literature is ambiguous about the substitution effect of private gardens on the use of parks (also called the ”compensation effect”). For instance, Talen (2010) and Caruso et al. (2018) find no significant relationship between the ownership of a private garden and the frequency of park visits. Finally, note that it can be shown that our theoretical results are unaltered if individuals have utility function $U(z, s, a)$ over a house service function $S$ that is a homothetic consumption bundle $S(s_h, s_g)$ of land consumption for houses and private gardens $s_h$ and $s_g$. In this case, private gardens substitute for parks, but the elasticity of substitution between private gardens and parks is the same as that between houses and parks.
problem in equation (1) can be rewritten as follows
\[
\psi = \max_s \frac{y - \tilde{z}(s, a, u)}{s}
\]  
(2)

The equilibrium housing slot size is given by the first-order condition
\[
\tilde{z}(s, a, u) - s\tilde{z}(s, a, u) = 0
\]  
(3)

We denote the solution for equation (3) as \( \hat{s}(y, a, u) \). Households’ optimal consumption are given by the functions \( \tilde{s}(y, a, u) \) and \( \tilde{z}(y, a, u) \) while the optimal bid rent is given by \( \hat{\psi}(y, a, u) \). Ceteris paribus, the equilibrium housing slot \( \hat{s} \) increases with distance to CBD (i.e. lower \( y \)) and decreases with amenity level \( a \). By the envelope theorem, the bid rent \( \hat{\psi} \) increases with disposable income \( y \) and amenity \( a \) and decreases with reservation utility \( u \); that is, \( \hat{\psi}_y, \hat{\psi}_a > 0 \), while \( \hat{\psi}_u < 0 \).

A competitive land market equilibrium is defined as the set of functions \((z, s, R, n)\) and scalars \((b, N, u)\) satisfying the following four conditions. First, individuals choose their optimal consumption: \( z = \tilde{z}(y, a, u) \) and \( s = \tilde{s}(y, a, u) \). Second, land is allocated to the highest bidder: \( R = \max\{\hat{\psi}(y, a, u), R_A\} \), with \( R = \hat{\psi}(y, a, u) \) if \( n > 0 \), and \( R = R_A \) if \( n = 0 \). Third, the land market clears everywhere: \( n\tilde{s}(y, a, u) = (1 - g) \) if \( n > 0 \). Finally, the total population conforms to its density: \( N = \int_0^b n \ell(r)dr \). Here, \( N \) is taken as exogenous in a closed city model, while \( u \) is exogenous in an open city. Within a city, equilibrium land rents are given by the winning bids such that \( R = \hat{\psi}(y, a, u) \). Since bid rents \( \psi \) increase with net income \( y \) and amenities \( a \), the equilibrium land rent \( R \) falls with distance from the CBD but rises with the proportion of green urban area.

It is worth noting the restriction of the spatial distribution of green urban amenity on the land market equilibrium. In equilibrium, land rents must exceed \( R_A \) for any location \( r \in [0, b] \) and be equal to it at the equilibrium city border \( b^e \). To simplify the exposition, we assume that \( R^e(r) \) crosses \( R_A \) from above at \( r = b^e \), which occurs if \( \hat{\psi}(y, a, u) \) lies above \( R_A \) in the CBD and falls in \( r \). A sufficient condition is given by
\[
\hat{\psi}(w, 0, u) > R_A, \quad -\hat{\psi}_y \frac{dt}{dr} + \alpha \hat{\psi}_a \frac{dx}{dr} < 0.
\]
After some reshuffling, this gives

\[ w > \tilde{z}(w, 0, u) + R_A \tilde{s}(w, 0, u), \quad (4) \]
\[ \frac{dt}{dr} > -\alpha \tilde{z} \frac{dx}{dr}. \quad (5) \]

These sufficient conditions imply that (1) urban productivity is sufficiently high for a city to exist in the absence of green urban areas and (2) green urban areas do not have excessively steep density profiles or do not yield too much spatial variation in amenities. Sufficiently high wages \( w \) and a low amenity parameter \( \alpha \) guarantee these conditions. Under those conditions, a spatial equilibrium exists and is unique. The equilibrium city border \( b^e \) is given by the unique solution of the land arbitrage condition: \( R(b^e) = R_A \).

The equilibrium population density is equal to \( n^e = (1 - g)/\tilde{s}(y, a, u) \geq 0 \), while the equilibrium population aggregates the population density across the urban area as

\[ N^e = \int_0^{b^e} \frac{1 - \beta x}{\tilde{s}(y, a, u)} 2\pi rd = \int_0^{b^e} \frac{1 - \beta x}{\tilde{s}\psi(y, a, u), y, a} 2\pi rd. \]

To obtain more analytical results, we will specify narrower classes of preferences in the next subsection: Cobb-Douglas and hyperbolic.

### 3.2 Cobb-Douglas preferences

We first consider the homothetic Cobb-Douglas utility,

\[ U(z, s, a) = \epsilon \chi z^{1-\phi-\varphi} s^\phi e^{a\varphi}, \quad (6) \]

with \( \phi, \varphi, (1 - \phi - \varphi) \in (0, 1) \). The parameters \( \phi \) and \( \varphi \) measure the preferences for residential space and green amenity. In reference to the next sections about estimation and welfare valuation, this definition also encompasses the presence of observable and unobservable heterogeneity \( \chi \) in the preferences (culture, family size) or specific characteristics of the city (altitude, temperature) as well as unobservable heterogeneity or measurement errors \( \epsilon \). We further assume that the transport cost \( t = w(1 - e^{-\tau(r)}) \) where \( \tau(r) \) is a function of distance to the CBD. The net income is given by \( y = w - t = we^{-\tau(r)} \). For simplicity, we assume the quadratic form \( \tau(r) = \tau_1 \times r + \tau_2 \times r^2 \). We can further standardize the amenity value \( \alpha = 1 \) and consider \( \beta \) as land use intensity to provide one unit for green amenities. We obtain the
equilibrium housing slot size

\[ \hat{s} = \left( \frac{1 - \varphi}{1 - \varphi - \phi} \right)^{1 - \varphi - \phi} \left( \frac{u}{\epsilon \chi} (w e^{-\tau(r)})^{-(1-\varphi \phi)} e^{-\epsilon \chi} \right)^{1 \phi}. \]  

(7)

Accordingly, residents have larger land plots for cities with smaller incomes \( w \), larger distances between residences and the CBD \( r \), smaller green urban areas \( g \), higher outside utility \( \bar{u} \), and smaller observable characteristics \( \chi \).

### 3.3 Hyperbolic preferences

We also exploit the hyperbolic preferences studied in Mossay and Picard (2011):

\[ U(z, s, a) = z - \frac{\theta}{2s} + a + \epsilon + \chi \]  

(8)

where \( \theta \) measures the preferences for residential space\(^7\) and \( \epsilon \) and \( \chi \) account for potential heterogeneity or measurement error. Accordingly, we obtain the consumption \( \hat{s} = \theta / (y + a + \chi + \epsilon - u) \), \( \hat{z} = (y - a - \chi - \epsilon + u) / 2 \) and land value \( \hat{\Psi} = (y + a + \chi + \epsilon - u)^2 / (2\theta) \).

We focus on the case of positive consumption so that \( y - a - \chi - \epsilon + u > 0 \). We assume that the transport cost is proportional to the average wage in the city \( t = w \times \tau(r) \), where \( \tau(r) \) is a function of distance to the CBD. Green area amenities are given by \( a = \alpha x \), which can be written as a function of green urban areas \( g \) as \( a = \alpha g / \beta \), where \( \alpha \) and \( \beta \) are green amenity and land use intensity parameters, respectively. We can further standardize the amenity value \( \alpha = 1 \) and consider \( \beta \) as land use intensity to provide one unit for green amenities. We obtain the inverse of housing slot size in equilibrium as given below:

\[ \frac{1}{\hat{s}} = \frac{1}{\theta} \left( w - w \times \tau(r) + \frac{\alpha}{\beta} g - u + \chi + \epsilon \right) \]  

(9)

The following sections apply those theoretical results to the data on European cities. We first describe our data, then proceed to the estimation and the computation of counter-factual exercises.

\(^7\)This yields a demand for residential space that has a price elasticity between one and zero (see Mossay and Picard 2011).
4 Data

We utilize two main databases. The first dataset is the population grid from Eurostat. The second dataset is the Urban Atlas implemented by the Global Monitoring for Environment and Security (GMES) service and provided by the European Environment Agency (EEA), for the time period 2005-2007. The Urban Atlas provides a classification of city zones that allows for a comparison of the density of residential areas, commercial and industrial zones and extent of green areas. The Urban Atlas uses Earth observation satellite images with 2.5 m spatial resolution.\(^8\) According to the GMES, the dataset covers the functional urban areas (FUAs) of the EU cities with at least 100,000 inhabitants.\(^9\) FUAs include land with both commuting distance and time below the critical levels defined by Eurostat.\(^10\) The dataset includes all capital cities and covers nearly 300 of the most populous towns and cities in Europe (EU 27).\(^11\)

In this paper, we use the data on “green urban areas” (class 141), which are defined as artificial nonagricultural vegetated areas. They consist of areas with planted vegetation that is regularly worked and/or strongly influenced by humans. More precisely, first, green urban areas include public green areas used predominantly for recreational use (gardens, zoos, parks, castle parks, cemeteries, etc.). Second, suburban natural areas that have become and are managed as urban parks are included as green urban areas. Finally, green urban areas also include forest and green areas that extend from the surroundings into urban areas with at least two sides being bordered by urban areas and structures and containing visible traces of recreational use. Importantly, for our study, green urban areas do not include private gardens within housing areas, buildings within parks, such as castles or museums, patches of natural vegetation or agricultural areas enclosed by built-up areas without being managed as green urban areas. It must be noted that green urban areas belong to the Urban Atlas’ class of ”artificial surfaces”, which includes all nonagricultural land devoted to human activities.\(^12\)

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\(^8\)GMES maps have a 100-times higher resolution than that of traditional maps in the CORINE Land Cover inventory produced since 1990.


\(^10\)See the definition in the Urban Audit in EEA, 2015, and the details in Appendix B.

\(^11\)Austria, Belgium, France, Germany, Bulgaria, Cyprus, the Czech Republic, Denmark, Estonia, Finland, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom.

\(^12\)In addition to green urban areas, artificial surfaces include urban areas with dominant residential use, inner city areas with a central business district and residential use, industrial, commercial, public, military and private units, transport units, mines, dump and construction sites, and sports and leisure facilities.
This class is distinguished from the agricultural, seminatural areas and wetlands, forest areas and water areas devoted to nonurban activities.

Figure 1: Berlin Land Use maps

We select the (oldest) town hall locations as the CBDs. Then, we create a set of annuli (rings) around each CBD at 100 m intervals. We define the "annulus land area" as the intersection of the annulus and the land within the urban zone area reported by the GMES. This area includes artificial surfaces, agriculture, seminatural areas, wetlands and forest but does not include water areas because those seas and oceans are not appropriate for potential human dwellings. We then compute the share of green urban area as the ratio of the surface of green urban area to the total land in the annulus land area for each annulus. Figure 1 displays the land uses of green urban areas (green color) for Berlin. Whereas urban theoretical models usually assume a neat frontier between residential and nonresidential spaces, urban data do not provide a clear separation between residential locations and agricultural areas and forests. In this paper, we choose to fix the city borders to the annulus for which the ratio of residential surfaces over the annulus land area falls below 20%. Residential surfaces include urban areas with dominant residential use and inner city areas with a central business district.
and residential use. They are shown in red in Figure 1. We define the distance from the CBD, dist.

Table 1: Summary statistics

<table>
<thead>
<tr>
<th></th>
<th>average</th>
<th>sd</th>
<th>min</th>
<th>max</th>
<th>obs.</th>
</tr>
</thead>
<tbody>
<tr>
<td>City border (km)</td>
<td>4.3</td>
<td>3.2</td>
<td>1.0</td>
<td>24.0</td>
<td>305</td>
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<td>City area (km²)</td>
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<td>174</td>
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<td>Number of annuli</td>
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<td>32</td>
<td>10</td>
<td>240</td>
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<tr>
<td>Population in FUA (millions)</td>
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<td>1.29</td>
<td>0.06</td>
<td>12.10</td>
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<tr>
<td>Population in CGC (millions): all cities</td>
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<td>0.79</td>
<td>0.03</td>
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<td>GDP per capita (€1000/hab.)</td>
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<td>13.06</td>
<td>6.00</td>
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<tr>
<td>Household income (€1000/hab.)</td>
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<td>5.63</td>
<td>3.70</td>
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<td>Density (hab./100m²)</td>
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<td>Residential Space (100m²)</td>
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<td>0.44</td>
<td>0.21</td>
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<td>Average temperature at Jan 01 (°C)</td>
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<td>Average temperature at July 01 (°C)</td>
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<td>12.27</td>
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<td>Average daily precipitation (mm/day)</td>
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<td>Share of Urban Green Land (%)</td>
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<td>Share of Residential Land (%)</td>
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<td>Share of Industrial and Public Land (%)</td>
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<td>6.02</td>
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<tr>
<td>Share of Sport and Leisure Land (%)</td>
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<td>3.21</td>
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<tr>
<td>Share of Forest Land (%)</td>
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<td>0.00</td>
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<tr>
<td>Share of Agricultural Land (%)</td>
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<tr>
<td>Share of Forest Land within 100m buffer (%)</td>
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<td>2.04</td>
<td>0.00</td>
<td>13.42</td>
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<tr>
<td>Share of Agricultural Land within 100m buffer (%)</td>
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<td>5.66</td>
<td>0.00</td>
<td>33.19</td>
<td>304</td>
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</table>

Note: The GMES database released on May 2010 reports only 301 FUAs for the time period 2005-2007. We use the Nadaraya-Watson Gaussian Kernel to smooth variations of annuli values. GDP per inhabitants and Household income are taken from Regional Economic Accounts from Eurostat at NUTS3 and NUTS2 level respectively. Note that in Eurostat database, household income level exists only at NUTS2 level. In eurostat database for household income at NUTS2, there is no data for Luxembourg (NUTS2 code LU00); therefore, there is only 304 cities instead of 305 cities. The number of inhabitants in each annuli is calculated based on Eurostat Population Grid. As Eurostat Population Grid 2006 does not cover Cyprus; hence, we also drop the city cy001llefkosia in our database. The total number of annuli are calculated for 303 cities excluding lu001lluxembourg and cy001llefkosia. For city geographical controls, we take into account the average for period 1995-2010 for each city.

In addition to the GMES, we use the population density from the European population grid. We calculate the population mass at each distance to the city center and redistribute the population to the residential area in each annulus. Because the Eurostat population grid does not cover Cyprus, we exclude Lefkosia, Cyprus. For the income level of a city, we use the household net income at the NUTS2 level, as reported in the Eurostat’s Regional Economic Accounts, which provides the finest detail on household net income. Our results are robust to the use of the city’s per capita GDP at the NUTS3 level. Other measures

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13The use of other thresholds does not lead to qualitative differences in our empirical results.
16Residential areas are called ‘urban fabrics’ in the GMES.
17See Supplementary Material.
of cities’ exogenous geographical characteristics are taken from the E-OBS database.\textsuperscript{18} We control for these exogenous geographical characteristics because they may affect residential choices. We finally measure the city populations as the number (millions) of inhabitants living in the city and greater city (CGC) areas, as defined and reported in the Eurostat databases.\textsuperscript{19} Table 1 presents the summary statistics.

In this paper, we mostly use the household income that measures the \textit{per capita} income net of all income taxes and at the NUTS2 level. Household incomes vary greatly across EU cities, from €3,700 per inhabitant to €30,900 per inhabitant. The average income is €15,460. Household income represents slightly more than one-half of the per capita production value (NUTS3), which reflects the high tax wedge between production cost and net income in the EU. The share of urban green, on average, accounts for approximately 6.5% of the total surface of city areas. Cities have a rather heterogeneous share of green urban areas. In our sample, the city with lowest share of green urban area (0.62%) is Limerick, Ireland, and the city with the highest share (42.6%) is Karlovy Vary, Czech Republic.\textsuperscript{20} City elevation also varies greatly, from two meters below sea level in Amsterdam, the Netherlands, to 1,614 meters above sea level in the mountainous city of Innsbruck, Austria. European cities belong to a mild climate zone, with temperatures varying between −8 and +28 degrees Celsius at the lowest and highest day temperature in winter and summer (measured on January 1 and July 1, respectively, for the period 1995-2000).\textsuperscript{21} The average population density is approximately 4,400 inhabitants per square kilometer and ranges from 1,000 to 9,800 inhabitants per square kilometer. These numbers are reasonable because the database concentrates on the core of urban areas with no agricultural or seminatural land use.

In the next section, we estimate residents’ land use under the specification of Cobb-Douglas preferences. Those are convenient and popular in urban economics. We then present the same analysis for hyperbolic preferences.

\textsuperscript{18}The E-OBS database provides detailed data on the daily temperature, daily precipitation, sea level pressure and elevation across Europe. We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu).

\textsuperscript{19}For more details, see metadata files for urb\_esms in the Urban Audit database of the Eurostat website.

\textsuperscript{20}The latter is a spa resort city, which offers many green areas to its visitors. The former city includes few land surfaces classified as green urban areas because it also has many agricultural and seminatural lands that can be used for urban green amenities. These outliers do not affect our results.

\textsuperscript{21}We use observations from the E-OBS databases from the EU-FP6 project (for details, see the references). Our samples do not contain some northern European cities in Iceland and Norway.
We first estimate the model with Cobb-Douglass preferences. Taking the natural logarithm of (7), we obtain the following residential land use:

\[
\ln \hat{s} = \ln \left( \frac{1 - \varphi - \phi}{1 - \varphi} \right) - \frac{1 - \varphi - \phi}{\phi} \ln \varphi - \frac{1 - \varphi - \phi}{\phi} \ln w
\]

\[
+ \frac{1 - \varphi - \phi}{\phi} \tau_1 t + \frac{1 - \varphi - \phi}{\phi} \tau_2 r^2 - \frac{\varphi}{\phi \beta} g + \frac{1}{\phi} \ln \bar{u} - \frac{1}{\phi} \ln \chi - \frac{1}{\phi} \ln \epsilon.
\]

From this, we build a regression model of (log of) residential land use:

\[
\ln(s_{ijc}) = \vartheta_0 + \vartheta_1 \ln w_{jc} + \vartheta_2 \text{dist}_{ijc} + \vartheta_3 \text{dist}^2_{ijc} + \vartheta_4 g_{ijc} + \vartheta_5 I_c + \vartheta_6 \text{X}_{jc} + \vartheta_7 A_{ijc} + \varepsilon_{ijc}
\]

for the observations of annulus \(i\) in city \(j\) of country \(c\). We measure the city wage \(w_{jc}\) by the per capita household net wage in the NUTS2 areas\(^{22}\) and the green urban areas \(g_{ijc}\) by the land share of green urban areas. Given the language, cultural and administrative barriers, we consider that individuals freely move across cities only within the same country. Thus, the country utility level is captured by the vector of country dummies \(I_c\). Finally, vector \(X_{jc}\) controls for observed city characteristics, such as elevation, rainfall and temperature. Vector \(A_{ijc}\) controls for observed amenities in each annulus, such as the shares of sport leisure facilities and industrial lands and the shares of forest and agricultural lands within a 100 m distance from the residential areas.

A potential endogeneity issue arises because the choices for residents’ land use and planners’ green urban areas are intertwined. Indeed, urban planners are expected to organize green urban areas as a function of surrounding population densities and therefore residents’ land use. To check for such a reverse causality, we use the historical level of urban green areas as indicative of the current levels. The main idea behind using historical urban green area information is that once an urban green area is developed, it is rarely changed. In fact, many urban green areas in Europe were provided decades ago and have remained intact.

\(^{22}\)In this text, city wages are measured by the incomes net of taxes at the NUTS2 level. Net incomes closely reflect the budget constraints faced by residents in their land use choices. However, NUTS2 encompasses larger areas than the cover of many cities, which may downward bias city income values. In Appendix C, we perform the same analysis with the production value at the NUTS3 level, which includes taxes. The results are similar except the values should be interpreted differently.
Two well-known examples are Hyde Park in London, created in the 16\textsuperscript{th} century by Henry VIII and originally intended for hunting, and the ‘Jardin du Luxembour’g, which was first built as a private garden of Queen Marie de Medici in the early 17\textsuperscript{th} century. Both private parks were later converted to public green areas by public authorities and are still freely accessible nowadays to London and Paris residents. This argument holds for the numerous smaller parks. Because of this issue, we build an instrument for the share of urban green areas using the historical values of an older database of land cover, namely CORINE Land Cover 1990. However, as this database reports fewer European countries and uses a coarser spatial grid, it produces fewer observations and adds measurement errors. The approach to match the two databases is detailed in Appendix A.

The results are reported in Table 2. Columns (1) to (4) display OLS estimates without instrument variables. In all columns, the coefficient estimates are consistent with our model predictions: residents use larger land plots for smaller city income, larger distance between residences and the CBD and smaller green urban areas. The results are robust after controlling for country fixed effects, city geographical conditions, such as elevation, rainfall and temperature (see Columns (2) and (3)), and different types of amenities within annuli (see Column (4)). To account for the above endogeneity issue, Columns (5) to (8) display the same estimates after instrumenting the share of urban green areas with its historical value from the CORINE Land Cover 1990 database. The IV regression reports slightly stronger effects of urban green areas on the residential slot size than those of the OLS regressions, which is intuitive because the historical levels of urban green areas were lower than the current ones. We also apply the Wu-Hausman test for endogeneity (reported in Appendix A). The Wu-Hausman test coefficient is not significant at the 90% confidence level, which supports the alternative hypothesis of absence of endogeneity. This suggests that endogeneity may not be a critical issue in our analysis. OLS and IV results show significant coefficients for the share of green urban area amenities at approximately 2.2 before including the control and in the range 1.7 – 1.8 after including controls. This finding implies that, ceteris paribus, residents in annuli with no green urban areas use 14\% more land than those residing in annuli with the average share of green urban area.\textsuperscript{23} Population densities diminish in the same proportions. According to this empirical estimation, green urban areas are an important factor explaining the use of residential land and population density.

We now apply the same analysis for the hyperbolic preference model. We estimate the

\textsuperscript{23}For this, we compute \( s_{ijc}/s_{ivj} = e^{\theta s(g_{ijc} - g_{ijc}')} \), with \( g_{ijc} = 0 \) and 0.07.
Table 2: Residents’ land use under Cobb-Douglas preference

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<th>Improve in Ln Residential Space</th>
<th>OLS</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>IV</th>
<th>(5)</th>
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<td>10,848</td>
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</table>

*Note: Significance levels are denoted by * for p<0.1, ** for p<0.05 and *** for p<0.01. Standard errors are clustered at city level. The row “df” reports the degree of freedom. Here, we use the Household income taken from Regional Economic Accounts from Eurostat at NUTS2 level with adjustment to purchasing power standard (PPS) as the proxy for city income level, and it is measured in €100,000. The distance to CBD is measured in 10 kilometres. The inverse of residential space is calculated by dividing the number of inhabitants in each annuli with annulus areas net of its urban green space. We exclude Cyrus and Luxembourg as the Eurostat population grid database does not cover Cyrus and the household income data at NUTS2 of Eurostat does not cover Luxembourg. United Kingdom and Finland are also excluded as they are not covered by Corine Land Cover 1990. City boundary is chosen at 20% cut-off point. For city control, we take into account the elevation, average rain fall, average temperature in Jan 01 and average temperature in July 01 for period 1995-2010. City amenity controls include the share of industrial, sport and leisure land use as well as the share of forest and agriculture land within 100 meters buffer from residential area.*
residential density with the regression

\[
\frac{1}{s_{ijc}} = \vartheta_0 + \vartheta_1 w_{ic} + \vartheta_2 (r_{ijc} \times w_{ic}) + \vartheta_3 (r_{ijc}^2 \times w_{ic}) + \vartheta_4 g_{ijc} + \vartheta_5 I_c + \vartheta_6 X_{jc} + \vartheta_7 A_{ijc} + \epsilon_{ijc}
\]

where \( i \) is the location of the annuli within the city border, \( j \) is the city and \( c \) is the country where the city belongs to. Distances, city incomes and controls are measured as in the previous subsection. The main differences lie in the inverse function on the left hand side and the cross products of distance and income on the right hand side.

Table 3 reports the regression results. Columns (1) to (4) display OLS estimates without instrument variables and Columns (5) to (8) with the instrument based historical values in the CORINE Land Cover 1990 database. The analysis yields the same conclusion as above as coefficient estimates are consistent with the model predictions: residents use larger land plots for smaller city income, a larger distance between residences and the CBD and smaller green urban areas. The results are robust to country fixed effects, city geographical conditions and presence of other amenities. Note that, after controlling for all other amenities, the square of the distance to the CBD loses its significance and suggests some linearity in transportation costs. The IV regression reports a similar magnitude of the effects of urban green areas on the residential slot size. The Wu-Hausman test coefficient is shown to be not significant at the 90% confidence level (see Appendix A). This confirms that endogeneity may not be a severe issue in our analysis. Both the OLS and IV results show significant coefficients for the share of green urban area amenities for approximately 2.9 – 3.2 before including the control and 2.4 – 2.7 after including all other controls. This finding implies that, ceteris paribus, residents in annuli with no green urban areas use approximately 19 – 22% more land than those residing in annuli with the average share of green urban area. Those changes are slightly higher than those under Cobb-Douglas preferences.

6 Welfare valuation

In this section, we use the previous regression models to quantify the value of green urban areas with a focus on the general equilibrium effect. We recover all parameters of our theoretical model and run several counterfactual analyses. In particular, we build counterfactuals where half of the green urban areas are deleted in every annulus and are either

\[
\text{We compute } \frac{1}{s_{ijc}} - \frac{1}{s_{ijc}'} = \vartheta_4 (g_{ijc} - g'_{ijc}), \text{ with } g_{ijc} = 0.07 \text{ and } g'_{ijc} = 0 \text{ and on average } s_{ijc} \text{ is at 0.95 (100 m}^2/\text{hab}.).\]
Table 3: Hyperbolic residents’ land use regression results

<table>
<thead>
<tr>
<th></th>
<th>OLS</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
</tr>
<tr>
<td></td>
<td>(0.813)</td>
<td>(2.011)</td>
</tr>
<tr>
<td></td>
<td>(1.783)</td>
<td>(1.713)</td>
</tr>
<tr>
<td>Distance to CBD square × Income</td>
<td>4.344 ***</td>
<td>3.645 ***</td>
</tr>
<tr>
<td></td>
<td>(1.162)</td>
<td>(1.346)</td>
</tr>
<tr>
<td>Share of Urban Green</td>
<td>3.190 ***</td>
<td>2.930 ***</td>
</tr>
<tr>
<td></td>
<td>(0.701)</td>
<td>(0.405)</td>
</tr>
<tr>
<td>Country FE</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>City Geographical Controls</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Annull Amenity Controls</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Sample</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Observations</td>
<td>10,853</td>
<td>10,853</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.131</td>
<td>0.455</td>
</tr>
<tr>
<td>Residual Std. Error</td>
<td>0.946</td>
<td>0.749</td>
</tr>
<tr>
<td>df</td>
<td>10,848</td>
<td>10,827</td>
</tr>
<tr>
<td>F Statistic</td>
<td>33.38 ***</td>
<td>24.61 ***</td>
</tr>
</tbody>
</table>

Note: Significance levels are denoted by * for p<0.1, ** for p<0.05 and *** for p<0.01. Standard errors are clustered at city level. The row “df” reports the degree of freedom. Here, we use the Household income taken from Regional Economic Accounts from Eurostat at NUTS2 level with adjustment to purchasing power standard (PPS) as the proxy for city income level, and it is measured in €100,000. The distance to CBD is measured in 10 kilometres. The inverse of space is calculated by divided number of inhabitants in each annuli with the areas within the annuli minus the areas using as urban green (in 100 meters). We exclude Cyrus and Luxembourg as the Eurostat population grid database does not cover Cyrus and the household income data at NUTS2 of Eurostat does not cover Luxembourg, United Kingdom and Finland are also excluded as they are not covered by Corine Land Cover 1990. City boundary is chosen at 20% cut-off point. For city control, we take into account the elevation, average rain fall, average temperature in Jan 01 and average temperature in July 01 for period 1995-2010. City amenity controls include the share of industrial, sport and leisure land use as well as the share of forest and agriculture land within 100 meters buffer from residential area.
left unused or converted to new residential land. This counterfactual is not marginal and leads to reallocation of residents and changes in residential spaces. We can then evaluate the changes in the residential land use and consumption of goods, population density, land rents and utility levels for each city. To express utility changes more intuitively, we measure the cost to residents by their incentives to leave the city and the compensating variation wage (subsidy or tax) that they must receive to maintain their utility levels. The difference between the status quo wage level and the new compensating variation income measures the willingness to pay expressed by the household (Sieg et al. (2004)). By the same token, we discuss the distribution of the effect of green urban areas between cities and within their extents. This analysis is a useful exercise because it informs policy makers about the impact of urban green areas on city structures and sizes.

We recover the model parameters from the estimated coefficient of residents’ land use using the values of $\vartheta_0$, $\vartheta_1$, $\vartheta_2$, $\vartheta_3$ and $\vartheta_4$ from Column (8) in Table 2 and Table 3 for Cobb-Douglas and hyperbolic utility function respectively. Country utility levels are recovered from the parameters $\vartheta_5c$ and the constant term $\vartheta_0$. Our baseline model and counterfactuals use the observed distance to the city center, city and country characteristics and local (nongreen) amenities. The baseline model simulates the variables under study using those estimated parameters and the observed characteristics (distance to CBD, wage, green urban areas, etc.). The counterfactual exercises investigate the impact of canceling 50% of the urban green areas in each annulus of each city, keeping the same observed characteristics. Counterfactual exercise 1 considers open cities where utility levels are maintained. This helps us discuss a long-term and unregulated perspective, where urban planners do not impose restrictions on workers’ mobility within and between cities. Counterfactual exercise 2 considers closed cities with exogenous city populations. The study of closed cities can be appropriate in evaluating policy changes that occur simultaneously in all cities, such as changes in EU policies. Here, our aim is to discuss a midterm or regulated perspective, where urban planners are able to restrict workers’ mobility between cities but allow residents’ land use to change. To give a relevant measure of utility change, we also compute the compensating variation wage as the city wage that maintains the baseline utility level when we remove green urban areas and the corresponding willingness to pay. Details are relegated to Appendix B.

25 Cheshire and Shepard (2002) also use the closed city model to analyze the welfare effects of policy changes in the UK.
6.1 Baseline model

The main characteristics of the baseline model are displayed in Table 4. The first column reports the number of cities. The other columns report the average and standard deviation over the city averages, which are themselves computed from the set of each city annuli using the baseline model parameters. The second and third columns show the consumption of composite goods and housing by households, while the fourth column displays the net income. The difference between this column and the sum of the two previous columns accounts for commuting costs.

Table 4: Baseline model results

<table>
<thead>
<tr>
<th>Cities</th>
<th>Composite Goods ((Z)) (€1000)</th>
<th>Housing Rent ((R \times s)) (€1000)</th>
<th>Income ((W)) (€1000)</th>
<th>Residential Area ((km^2))</th>
<th>Green Area (GA) ((km^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cobb-Douglas preference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spatial heterogeneity</td>
<td>264</td>
<td>5.05</td>
<td>6.92</td>
<td>15.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.87)</td>
<td>(2.56)</td>
<td>(5.87)</td>
<td>(48.91)</td>
</tr>
<tr>
<td></td>
<td>No spatial heterogeneity</td>
<td>264</td>
<td>5.03</td>
<td>6.89</td>
<td>15.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.86)</td>
<td>(2.55)</td>
<td>(5.87)</td>
<td>(48.91)</td>
</tr>
<tr>
<td></td>
<td>Hyperbolic preference</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spatial heterogeneity</td>
<td>264</td>
<td>5.22</td>
<td>8.12</td>
<td>15.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.86)</td>
<td>(4.60)</td>
<td>(5.87)</td>
<td>(48.91)</td>
</tr>
<tr>
<td></td>
<td>No spatial heterogeneity</td>
<td>264</td>
<td>5.01</td>
<td>8.32</td>
<td>15.22</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(6.01)</td>
<td>(3.64)</td>
<td>(5.87)</td>
<td>(48.91)</td>
</tr>
</tbody>
</table>

Note: The standard deviation is reported in the parenthesis. Household income is taken from Eurostat at NUTS2 level and is measured on purchasing power standard (PPS) at 1000€. More details on PPS measure, see Eurostat technical documents.

On average, individuals have €15,220 as disposable income and spend €6,920 for housing expenses, which accounts for approximately 45% of their net income under Cobb-Douglas preferences. Under hyperbolic preferences, individuals spend €8,120 for housing expenses, which is higher than under Cobb-Douglas preferences. Such a value is slightly above the average housing costs in European cities, which are approximately a quarter of the household income for both European rural and urban areas. The literature reports a range between 18% and 32%, with higher levels for urban areas and renters (Fahey et al, 2004, Davis and Ortalo-Magne, 2011). Our model differs from this literature because we do not take into account housing furniture and maintenance (5% of housing costs in Eurostats, 2015), we consider city cores, which have more expensive housing locations, and finally, we do not model the construction process.

The last two columns of Table 4 report the average residential area and green urban area across cities, the latter being approximately a fifth of the former. Interestingly, the table differentiates baselines when regression model errors are considered as measurement errors.
(no spatial heterogeneity) or unobserved spatial amenity (spatial heterogeneity). Measurement errors do not affect residents' decisions whereas the spatial amenity are considered by the residents who alter their consumption and housing decisions accordingly. The literature on structural estimation in Urban Economics often recovers the local amenity characteristics from the divergence between data and model predictions. The difference between the two approaches is here quite small. The approach with spatial heterogeneity slightly raises the dispersion of consumptions and rents because the later are endogenous decisions. For this reason, the subsequent analysis will be based on the assumption of spatial heterogeneity and standard deviations in parentheses will be dropped.

6.2 Counterfactual analysis

Our main results are displayed in Table 5, which shows the estimations of the baseline model (first row) and the counterfactual exercises (other rows) in two separate panels for the Cobb-Douglas and hyperbolic models. Every column reports the average over the city averages imputed from city annuli. The first five columns display the imputed residential surfaces, land rents on units of residential plots and green urban areas, population and relative utility.

The first row presents the baseline model characteristics that we compare with counterfactual exercises. The average city size of 0.31 million inhabitants is consistent with the statistics that most European cities are medium-sized (European Commission and UNHabitat (2017), Urban Audit, Eurostat). Residents' average use of space is approximately 95 m²; the measure is reasonable given that we consider the core of the most populous cities in the EU, which are the densest areas of the most urbanized parts of the EU. For the Cobb-Douglas model, the land rent per square meter is 93.41 €/m²/year on average for all cities. On average, the land values of green urban areas (102.32 €/m²/year) are higher than residential land prices. These values are imputed from the residential land price associated with each annulus. Because urban green areas are concentrated at close and intermediate distances to CBDs, they are surrounded by more expensive residential land plots. The average city size, average residential space and average population are similar in the hyperbolic model. The only difference lies the higher value of land rent per square meter: 143 €/m²/year on average for all cities. This reflects that hyperbolic preferences exhibit a higher income elasticity of demand residential lands.

²⁶They are more densely populated than US cities.
Open cities: Consider now our counterfactual exercise 1 where cities are open to migration and 50% of the green areas in every annulus are removed. The utility of city inhabitants is exogenous but the change in green amenities affects urban structures. On the one hand, suppose further that removed land is not (re)used, as indicated in the second row of each panel of Table 5. To keep the same utility level, residents must compensate for the decrease in urban green amenities by larger residential plots, which implies that a share of the population must migrate out of the city. In the Cobb-Douglas model, city residents increase their land use from 95 to 100 m\(^2\) on average (a rise of 5.3%), and the city population falls from 0.31 to 0.29 million (a loss of 6.5%). Land rents fall from 93.41 to 87.11 € per m\(^2\) and year (a fall of 6.74%). We compute the total loss in the land market to be approximately €147 million for an average city.\(^\text{27}\)

On the other hand suppose that green urban areas are converted into residential land, as shown in the third row of first panel of Table 5. In an average city, a new land supply of 2.26 km\(^2\) (half of the baseline green urban area 4.52 km\(^2\)) adds up on top of the baseline residential land supply of 25.29 km\(^2\); that is, an increase of 8.9% (see second panel). This increase is bigger than the above 5.3% space compensation that residents require without land conversion. As a result, the additional land supply attracts new city dwellers and the city population rises to 0.32 million on average. Residential land rents rise slightly to 87.64 € per m\(^2\) and year because the new land is supplied at more central locations and has higher value. We compute that, compared to the baseline model, the housing market increases its total value by nearly €55 million per year and city when we take into account converted areas.

Effects are slightly stronger in the hyperbolic model. In the absence of land conversion of green urban areas, city residents increase their residential land use by approximately 10% while city population falls by approximately 9.5% on average. Land values decline more steeply by about 9% (from 143 to 129 € per m\(^2\) per year). This situation results in a larger loss in the housing market for roughly €322 million in an average city. This stems from the higher sensitivity of the bid rent under hyperbolic preferences as it can be seen that residential land uses and prices change more. Also, the consumption of nonhousing goods also changes more under new equilibrium leading to a smaller budget for housing consumption (see subsection 3.4). In the case of land conversion into residential land, the

\(^{27}\)To estimate the total land rent loss, we multiply the city residential area of each annulus with the per-square-meter land rent loss between the baseline and counterfactual models. We then aggregate over the city, and compute the average over all cities.
residential land rents rise slightly to 131 € per m² per year because the new land is supplied at more central locations with higher land values. We compute that, compared to the baseline model, the housing market increases its total value by approximately €22 million per year and city when we take into account converted areas.

**Closed cities:** Consider now counterfactual exercise 2 with closed cities where city planners prohibit migration. What is the impact of reducing urban green areas by half? When there is no conversion of land, the utility of all residents decreases. Under Cobb-Douglas preferences, the average utility decreases from 1 to 0.94. Residential land rents decrease only by a small amount from 93.41 €/m²/year to 93.36€/m²/year, providing a total loss of €1.82 million per year. The decrease in utility combined with the change in land rent requires an increase from the baseline annual net income of €15,200 to the compensating-variation income of €16,650; that is, an rise of €1,430 (9.4%). As indicated in section 3.3, this is also the measure of general equilibrium WTP for canceling half of the urban green areas without land conversion. Multiplying this figure by the city population, residents would need to be compensated by a subsidy of €580 million for an average city. For reference, the general equilibrium WTP for closing all publicly accessible open spaces in Cheshire and Sheppard (2002) is £2,424 per household per year for the city of Reading, UK. Our average measure is not too far from this.

Regarding the hyperbolic model, the average utility drops from 1 to 0.84 with no conversion policy. Total residential land rents decline by a bigger amount of €19 million per year. This reduction in utility combined with the change in land rent requires an increase in the baseline annual net income of €970 (6.4%) per year per household, which is the WTP measure of an average household. This measure is slightly lower than the 9.4% found under Cobb-Douglas.

Suppose now that green urban areas are converted into residential land. Then, the residential land supply increases, land rents decreases and residents can use more land to compensate for the loss of green area amenities. Specifically, for Cobb-Douglas preferences, land rents drop by 9.6% to 84.47 €/m²/year and the total loss in housing market increases to €3.45 million per year. However, city residents enjoy both lower land rent and larger residential land plots, which increase their average utility level. They obtain a slightly higher

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28In an average city, there is a new land supply of 2.26 km² (half of 4.52 km²) on top of the baseline residential land supply of 25.29 km², an increase of 8.9%.
Table 5: City structure in closed and open cities with $g = 0.5 \times g_0$

<table>
<thead>
<tr>
<th>Cities (number)</th>
<th>$s$ (100 m$^2$/hab)</th>
<th>Land Rent (€/$m^2$/y)</th>
<th>Green value (€/$m^2$/y)</th>
<th>Pop. (mil.)</th>
<th>$U/O_b$</th>
<th>Comp. W (€/1000)</th>
<th>Total loss in housing market (€ mil.)</th>
<th>wage comp. (€ mil.)</th>
<th>pop. 1,000 hab.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cobb-Douglas model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline 0</td>
<td>264</td>
<td>0.95</td>
<td>93.41</td>
<td>102.32</td>
<td>0.31</td>
<td>1.00</td>
<td>146.61</td>
<td>0</td>
<td>20.39</td>
</tr>
<tr>
<td>Counterfactual 1: Open City</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban green conversion No</td>
<td>264</td>
<td>1.00</td>
<td>87.11</td>
<td>92.73</td>
<td>0.29</td>
<td>1.00</td>
<td>146.61</td>
<td>0</td>
<td>20.39</td>
</tr>
<tr>
<td>Yes</td>
<td>264</td>
<td>1.00</td>
<td>87.64</td>
<td>92.73</td>
<td>0.31</td>
<td>1.00</td>
<td>-54.74</td>
<td>0</td>
<td>-8.24</td>
</tr>
<tr>
<td>Counterfactual 2: Closed City</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban green conversion No</td>
<td>264</td>
<td>0.95</td>
<td>93.36</td>
<td>99.38</td>
<td>0.29</td>
<td>0.94</td>
<td>16.65</td>
<td>1.82</td>
<td>580.56</td>
</tr>
<tr>
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<td>264</td>
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<td>84.47</td>
<td>89.26</td>
<td>0.32</td>
<td>1.03</td>
<td>-198.56</td>
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</tr>
<tr>
<td><strong>Hyperbolic model</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline 0</td>
<td>264</td>
<td>0.96</td>
<td>143.14</td>
<td>172.33</td>
<td>0.31</td>
<td>1.00</td>
<td>322.08</td>
<td>0</td>
<td>21.55</td>
</tr>
<tr>
<td>Counterfactual 1: Open City</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Urban green conversion No</td>
<td>264</td>
<td>1.06</td>
<td>129.08</td>
<td>150.71</td>
<td>0.28</td>
<td>1.00</td>
<td>322.08</td>
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<td>21.55</td>
</tr>
<tr>
<td>Yes</td>
<td>264</td>
<td>1.05</td>
<td>131.74</td>
<td>150.71</td>
<td>0.31</td>
<td>1.00</td>
<td>22.99</td>
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<td>-6.60</td>
</tr>
<tr>
<td>Counterfactual 2: Closed City</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Urban green conversion No</td>
<td>264</td>
<td>0.96</td>
<td>142.38</td>
<td>161.94</td>
<td>0.31</td>
<td>0.84</td>
<td>16.19</td>
<td>19.45</td>
<td>315.31</td>
</tr>
<tr>
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<td>136.14</td>
<td>0.31</td>
<td>1.08</td>
<td>-202.02</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

Note: The standard deviations are not reported. Household income is taken from Eurostat at NUTS2 level and is measured on purchasing power standard (PPS) at 1000 $e$. More details on PPS measure, please check Eurostat technical documents. Population is calculated in million inhabitants. Utility is measured relatively to baseline average. Basically, we measure $U_{jc}/O_{baseline}^j = U_{jc}/[(1/N) \sum_{jc} U_{jc}^{baseline}] = u_{jc}^{1/\delta}/[(1/N) \sum_{jc} (u_{jc}^{baseline})^{1/\delta}]$ where $u_{jc}$ is calculated as in the above section.
average utility level (increase by 3%) and require a smaller compensating-variation wage of €14,570 per year to maintain their level of utility, which is equivalent to an income reduction of €650 per year. The results from hyperbolic preferences brings similar conclusions. Particularly, the land rents drop by 17% to 118 €/m$^2$/year, and the total loss in the housing market rises to €236 million per year. It is significantly a bigger loss compared to the Cobb-Douglas model. In latter case, the housing expenditure is a fixed proportion of households’ net income (net of commuting costs); hence, the total loss in housing market in a closed city with or without land conversion is relatively small since the population is unchanged.\footnote{so as the total expenditure on housing market} While in case of hyperbolic preference, the expenditure on housing and composite goods changes according to the supply of residential land. In fact, household increases their share of expenditure on composite goods and decrease the expenditure on housing significantly when green areas are erased, which results in a bigger loss in housing market value of residential land here. City residents reach a slightly higher average utility level (jump by 8%) and need a smaller compensating-variation wage of €14,730 per year to maintain their level of utility, which is equivalent to an income reduction of €490 per year, or equivalent to 3.2% of their annual income. Those results from both preferences are also in line with those of Cheshire and Sheppard (2002), who also found that the net effect of land use planning is negative and that allowing more residential developments is welfare improving.

To summarize, the effects of population reduction under open cities, the measures of compensating wage variations, and the corresponding WTP for an average household are robust under two preference specifications. The land prices computed are higher under hyperbolic preferences than Cobb-Douglas.

### 6.3 City income and CBD access

What type of cities are more sensitive to removing green urban areas? Where in the city are the changes more important? To answer these questions, we compare the impact of removing or converting green urban areas between cities of different incomes and population sizes as well as between inner city locations at different distances to the CBD. Toward this aim, Table\[6] reports the baseline wage (first row), the changes in the compensating-variation wages to sustain constant utility (next two rows), the baseline land rent to landlords (fourth row), and the landlords’ losses (last four rows) for the Cobb-Douglas and hyperbolic models. In the columns, we group cities by income quartiles (first four columns), by population
size quartiles (next four columns) and by quartiles of relative distances to the CBD (last four columns). The positive changes in compensating-variation wages can be interpreted as subsidies required to maintain the residents at their baseline equilibrium levels. Table 5 summarizes our results for open and closed cities when green urban areas are and aren’t converted residential land. All figures are aggregated from the same counterfactual exercise with the 50% reduction in the green urban areas presented in Table 5 and ??.

In open city systems, the reduction in green urban area amenities harms residents who partly leave the city. Since, city residents keep the same utility as in the countryside, they do not need any compensation to stay in cities. By contrast, landlords lose money. Under Cobb-Douglas preferences, if urban green areas are not converted to residential land, landlords lose €3.27 and €8.22 per m² and year in cities belonging to the bottom and upper income quartiles, respectively (see fifth row of Table 5). Similarly, they lose €5.21 and €7.90 per m² and year in cities belonging to the bottom and upper population quartiles, respectively. This result is explained by the fact that land value, city size and income are positively correlated. However, the absolute increase is higher as land demand is more sensitive. Landlords also lose €11.24 per m² and year in the central city quartile but only €3.89 per m² and year in the city periphery quartile, indicating that land rents decrease with distance from the CBD. This pattern remains approximately the same if urban green areas are converted to residential land (sixth row). The conversion of green urban areas mitigates the conclusions only to a small extent. The pattern is similar in case of hyperbolic preferences (Table 5).

Let us now consider closed cities in which migration is restricted and half of the green urban areas is removed (counterfactual exercise 2). Suppose initially that there is no land conversion (second and seventh rows). Under the Cobb-Douglas preferences of Table 6, residents require an increase in compensating-variation wages to stay in the city; that is, a subsidy, of €770 per year for the bottom city income quartile and €2,090 per year for the top quartile (second row). This increase represents up to 9.1% and 9.6% of the baseline incomes. These subsidies also increase with city population. One can check that larger cities require proportionally higher subsidies, which results from the higher losses incurred by the residents in larger cities. In case of hyperbolic preferences, residents require a subsidy of €930 per year for the bottom city income quartile and €980 per year for the top quartile. There are smaller differences in willingness to pay between income and population quantiles under hyperbolic preferences compared to Cobb-Douglas. The reason is that those differences are proportional to income levels in the case of Cobb-Douglas preferences, whereas they are not
Table 6: Counterfactual analysis: between- and within-city statistics

<table>
<thead>
<tr>
<th></th>
<th>Between cities</th>
<th></th>
<th>Within cities</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>City Income Quartiles</td>
<td>City Population Size Quartiles</td>
<td>Distance to CBD Quartiles</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0-0.25 0.25-0.50 0.50-0.75 0.75-1</td>
<td>0-0.25 0.25-0.50 0.50-0.75 0.75-1</td>
<td>0-0.25 0.25-0.50 0.50-0.75 0.75-1</td>
<td></td>
</tr>
<tr>
<td><strong>Cobb-Douglas model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline wage (€1000/hab/y)</td>
<td>8.19 12.27 17.71 22.93</td>
<td>12.36 14.97 15.85 17.72</td>
<td>16.71 16.62 16.64 16.54</td>
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<tr>
<td>WTP (€1000/hab/y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Counterfactual 2: Closed City Urban green conversion</td>
<td>No −0.77 −1.18 −1.67 −2.09 −1.28 −1.37 −1.33 −1.71</td>
<td>−1.60 −1.85 −1.47 −1.12</td>
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<td></td>
</tr>
<tr>
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<td>0.29 0.43 0.61 0.92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land rent baseline (€/m²/y)</td>
<td>49.73 94.59 104.09 126.23</td>
<td>73.45 85.55 100.08 114.56</td>
<td>176.38 114.34 80.06 63.85</td>
<td></td>
</tr>
<tr>
<td>Counterfactual 1: Open City Urban green conversion</td>
<td>No 3.27 6.30 7.49 8.22 5.21 5.33 6.54 7.90</td>
<td>11.24 8.69 5.23 3.89</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes 2.97 5.35 6.79 8.09 4.01 5.02 6.22 7.83</td>
<td>11.24 8.69 5.23 3.89</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counterfactual 2: Closed City Urban green conversion</td>
<td>No 0.05 0.08 0.04 0.01 0.01 0.03 0.06 0.09</td>
<td>0.08 1.27 −0.06 −0.45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes 4.69 9.04 10.51 11.67 8.43 7.87 8.83 10.71</td>
<td>15.47 11.71 7.49 5.92</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hyperbolic model</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Baseline wage (€1000/hab/y)</td>
<td>8.06 12.27 17.71 22.93</td>
<td>12.42 14.83 15.92 17.72</td>
<td>16.71 16.62 16.64 16.54</td>
<td></td>
</tr>
<tr>
<td>WTP (€1000/hab/y)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Counterfactual 2: Closed City Urban green conversion</td>
<td>No −0.93 −0.99 −0.99 −0.98 −1.05 −0.94 −0.89 −0.99</td>
<td>−1.06 −1.19 −0.95 −0.72</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yes 0.35 0.84 0.47 0.31 0.60 0.28 0.47 0.61</td>
<td>0.71 0.41 0.23 0.48</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Land rent baseline (€/m²/y)</td>
<td>106.46 197.38 156.05 111.90</td>
<td>97.13 102.80 156.96 215.66</td>
<td>285.27 181.97 117.27 95.48</td>
<td></td>
</tr>
<tr>
<td>Counterfactual 2: Closed City Urban green conversion</td>
<td>No 0.67 1.28 0.73 0.38 0.80 0.61 0.89 0.75</td>
<td>2.99 4.10 0.42 −1.14</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Note:** The standard deviations are not reported. The loss for landlord is accounted as the difference between new land rent equilibrium and land rent in baseline model 0.
in the case of the hyperbolic preferences (for details, see Appendix B). The subsidy in the case of hyperbolic preferences is not monotonic with distance to the city center, which is robust in both utility functions. Under Cobb-Douglas preferences, the subsidy first increases from €1,600 to €1,850 per year when one moves from the first to the second distance quartiles and then drops to €1,120 for the last distance quartile. Under hyperbolic preferences, the magnitude is smaller at €1,060 at the first distance quartile and €720 for the last distance quartile. This pattern reflects the geographical distribution of the share of green urban areas. It can finally be seen that landlords are not substantially harmed by the reduction in green urban areas when cities are closed and land is not converted.

Finally, suppose that the green urban areas are converted to residential land (third and eighth row), which increases the residential land supply and compensates residents for the lack of green area amenities. The changes in compensating-variation wages indicate that residents are better off in this situation. Low-income cities would accept lower compensating-variation wages, which means that they would therefore agree to pay a tax of €360 per year in the lowest city income quartiles and €900 per year in the highest (third row in Table 3). This tax is larger for peripheral residents. Finally, landlords are negatively affected by the additional supply of residential land (see eighth row). They are more impacted in the richest and the largest cities and at the most central locations.

### 6.4 Continuous changes

In the previous subsections, we have investigated land and welfare values when the planner uniformly erased 50% of green urban areas across city locations. In this subsection, we extend the analysis to the removal and creation of continuous shares of green urban areas. Zero removal is referred to the status-quo level. The creation of new green urban areas corresponds to a negative share of removed green urban areas. In this case, new green urban areas are assembled on available vacant land in the case of ‘no conversion’ while they replace residential land in the case of ‘conversion’.30

The changes in housing slot size and land rent per square meters are reported in Figure 2. It can be seen that most effects are roughly proportional to the changes in the share of green urban areas and similar in both preference setups. A 10% removal or creation of urban green areas leads to about 1.5% increase or decrease in house sizes (top panel) and about

---

30In this exercise, we do not consider the cost of converting residential land into green areas for simplicity. The exercise therefore gives a higher bound on the value of new green urban areas.
1% decrease or increase in residential land rents (bottom panel) when households are free
to choose house sizes. The only noticeable dissimilarity and non-linearity take place for the
land rents in closed cities with land conversion (bottom panel, green crosses). As residents
have more inelastic land demands under hyperbolic preferences, land prices decrease further
down when urban green areas are converted into new residential plots, and increase further
up when residential land is converted to green spaces.

Figure 3 presents the effects on the compensating wage variations, city population levels
and total residential land value. Most effects are roughly proportional to the changes in the
share of green urban areas and similar in both preference setups. In a first order approxi-
mation, the creation of new green urban areas has the opposite effect of their removal.

In closed cities with no land conversion, the removal of green urban areas decreases
residents utility and requires to pay them higher income to keep them indifferent with the
Figure 3: Robustness check with different levels of erasing green areas

(a) Cobb-Douglas

(b) Hyperbolic
baseline situation. Roughly, a 10% removal of urban green areas leads to an 2% change in equivalent income, i.e. subsidy of 2% of their incomes (see top panel, red squares). The landlords’ total loss remains very small whatever the erased or created green urban areas (bottom panel, red squares). In closed cities with land conversion, the removal of green urban areas reduces green amenities but increases land supply. A 10% removal of urban green areas leads to an equivalent income change of about -1.5% (top panel, green crosses). It induces no changes in total land value under Cobb-Douglas preferences but a decline of about 1.5% in total land value under hyperbolic preferences (bottom panel, green crosses). However, in open cities with no land conversion, a removal of 10% of urban green areas reduces the green amenities and entices about 2% of the population to emigrate (middle panel, blue circles) and implies a 1.5% loss for landlords. The opposite holds for the creation of new green areas. Finally, in open cities with land conversion, the removal of 10% of urban green areas reduces the green amenities and creates new residential land. It leads to immigration of about 0.7% of the population (middle panel, green triangles). It leads to a rise of about 0.5% in total land value under Cobb-Douglas preferences but yields a small and non-monotone changes under hyperbolic ones (bottom panel, green triangles).

To sum up, changes in green urban areas generally yields proportional changes in equivalent income, population and total land value. Those depends on the city openness and land conversion policy. An exception to this consists of the total land value in open cities with land conversion, which behaves non monotonically and differ between the two preferences specifications.

7 Conclusion

This paper studies the effects of land-intensive public green areas on city structures under competitive land markets. We employ monocentric urban land market frameworks with two different classes of utility functions—Cobb-Douglas and hyperbolic—to formalize the effects in residential land uses and households’ willingness to pay (WTP) from a substantial change in green urban areas. The model emphasizes the importance of incorporating the adjustments in housing markets under a nonmarginal change in urban green areas in measuring households’ WTP.

We first compute the equilibrium in residential land uses in the theoretical model and utilize the geographical land covers combined with actual population density to estimate the
model parameters. The historical level of green areas is used to instrument for the current level in order to control for the potential endogeneity in green provision. To quantify the value of green urban areas, we present a set of counterfactual exercises, where half of the green urban areas are removed. In case of the Cobb-Douglas preferences, we estimate that, on average, open cities lose more than 6.5% of their population and that landlords lose €147 million in each city and year if the green urban areas are not converted into residential land. Such a loss in population is robust for both the hyperbolic and Cobb-Douglas preferences, while the impact for the land market is higher in the hyperbolic case. If the erased green areas are converted into new residential land, the increase in total residential lands is sufficient to compensate locals with additional residential space and to attract new city dwellers. Compared to our baseline model, for Cobb-Douglas preferences, the housing market increases its total value by nearly €55 million per year and city.

In closed cities where the green urban areas are not converted, the willingness to pay to avoid such a policy is measured at €1,430 per person and year. The estimated results for hyperbolic preferences are similar at €1,110 per person per year. These amounts are significantly large at 9% and 6% of annual household income for Cobb-Douglas and hyperbolic preferences. However, when we allow for the land conversion, the green urban areas have a cost of 4.2% of annual household income for both preferences, implying that the opportunity costs of urban green areas are also substantial. These counterfactuals suggest an modest overprovision of green urban areas. The paper provides additional information on the city income and population characteristics and on the inner city location where such overprovision takes places.

While accounting for the general equilibrium effects of the land market equilibrium, our approach has obvious limitations. The first limitation is its reliance on the monocentric urban model. This limitation can be easily changed by including more than one business center in theoretical model\(^\text{31}\), however, in the empirical parts, a polycentric city analysis requires more intensive data on the location of job centers for every city. As most of our city samples are monocentric cities\(^\text{32}\) we think that monocentric urban areas are a reasonable simplification with tractable results. The second limitation is the heterogeneity in households’ preference for green amenity. We here consider a single class of households; therefore, our study is

\(^{31}\)One approach could be as in Lucas and Rossi-Hansberg (2002).
\(^{32}\)The OECD study on polycentric metropolitan cities only reports 18 European cities with two urban centers and only 6 with more than two urban cores (Barcelona, Paris, Lyon, Amsterdam, Stockholm and London) among our sample of more than 300 cities.
valid for a representative household. The effects of green amenity change in urban areas are calculated based on the long-run change in the land market. In the context of a durable housing structure, the adjustments of residential land use might take a considerable time. The dynamic effects in the housing market relating to the change in land-intensive amenity change are open for future research.
References


[17] E-OBS database (2017 release version). We acknowledge the E-OBS dataset from the EU-FP6 project ENSEMBLES (http://ensembles-eu.metoffice.com) and the data providers in the ECA&D project (http://www.ecad.eu).


Appendix A  First stage regression and Wu-Hausmann test for IV regressions

In this section, we report the first stage regression and the Wu-Hausman test for IV regression. We use the historical level of urban green spaces (land use code 141) in Corine Land Cover in 1990 as our instrument variable. To our knowledge, Corine Land Cover (CLC) was the first systematized report of land use over the whole Europe, and its earliest version was in 1990. However, there are two issues with CLC 1990. First, CLC 1990 did not cover UK, Sweden and Finland as those three countries only appeared in later version of Corine Land Cover in 2000 onward. Therefore, we need to drop the city samples belonging to these three countries. Second, as CLC covers not only urban area but also the rural and all lands in Europe. CLC resolution is much less precise than GMES Urban Atlas that covers only urban areas. This implies that several GMES observations are contained in each CORINE plot. To decrease the discrepancies, we use the land cover in CLC 2006 and GMES Urban Atlas 2006 and correct for the discrepancies between these two sets. We assume that the changes between Corine 2006 and Corine 1990 is the evolution of urban green, while the difference between Corine 2006 and GMES 2006 are just discrepancies in measurement. We adjust the Corine 1990 with these measurement errors before using it in the first stage regression.

We apply the Wu-Hausmann test for endogeneity. In the first stage, we regress \( g_{ijc} = \alpha g_{Corine90} + \varphi' Z + \nu_{ijc} \). In the second stage, we regress \( \ln s_{ijc} = \vartheta Z + \vartheta_4 g_{ijc} + \vartheta_{err} \hat{v}_{ijc} + \varepsilon_{ijc} \) where \( Z \) is the vector \((1, w, dist, I_c, X_{jc}, A_{ijc})\) and \( \hat{v}_{ijc} \) is the residuals from first stage regression. The Wu-Hausmann test for endogeneity requires that the coefficient of the latter residual is significant in the second stage regression. We perform this test first for the model with Cobb-Douglas preferences and then for the one with hyperbolic preferences.

Table \( \text{A.1} \) shows the first and second stage regression results for the Cobb-Douglas model. The columns sequentially include controls on country, city and anulus. The coefficient of the adjusted urban green from Corine 1990 is a very good predictor for the current level of urban green in GMES 2006, confirming that historical green space arrangements strongly

---

33CORINE Land Cover (CLC) 1990 does not cover the UK, Sweden and Finland. The database covers Austria, Belgium, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Montenegro, the Netherlands, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, and Turkey, out of which 23 countries are included in our data. For details, see CORINE Land Cover 1990 Metadata: [https://land.copernicus.eu/pan-european/corine-land-cover/clc-1990?tab=metadata](https://land.copernicus.eu/pan-european/corine-land-cover/clc-1990?tab=metadata) (Accessed May 02, 2018). To our knowledge, CLC 1990 is the oldest land use database that systematically covers all of European cities.
determine the current ones. The correlation is highly significant about 0.8. \( R^2 \) is close to 0.80. The Wu-Hausman test coefficient for endogeneity (\( \hat{v}_{ijc} \)) is not significant at 90% of confidence level, confirming the alternative hypothesis of absence of endogeneity. Table A.2 shows the first and second stage regression for the Hyperbolic preference model. Note that in this model, the second stage explains the density \( 1/s_{ijc} \). Again the coefficient on adjusted urban green in Corine 1990 is a very good predictors for the current level of urban green. The Wu-Hausman test coefficient for endogeneity (\( \hat{v}_{ijc} \)) is also not significant at 90% of confidence level. These two exercises strongly suggest that endogeneity is not a critical issue in our analysis.

Table A.1: Cobb-Douglas - First stage regression and Wu-Hausman test for endogeneity

<table>
<thead>
<tr>
<th>First stage regression</th>
<th>Dependent variable: Share of green area in GMES 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>Adjusted Share of green area in Corine 1990</td>
<td>0.802***</td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
</tr>
<tr>
<td>Adjusted ( R^2 )</td>
<td>0.760</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Wu-Hausman test for endogeneity</th>
<th>Dependent variable: Ln Residential Space</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
</tr>
<tr>
<td>( \hat{v}_{error} )</td>
<td>-0.421</td>
</tr>
<tr>
<td></td>
<td>(0.885)</td>
</tr>
</tbody>
</table>

| Country FE | No | Yes | Yes | Yes |
| City Geographical Controls | No | No | Yes | Yes |
| Annuili Amenity Controls | No | No | No | Yes |
| Sample | All | All | All | All |
| Observations | 10,853 | 10,853 | 10,853 | 10,853 |

Note: We use the following procedure to test for endogeneity. First Stage: \( g_{ijc} = \sigma_{Corine90} + \theta Z + \hat{v}_{ijc} \). Second Stage: \( \ln s_{ijc} = \theta Z + \hat{v}_{ijc} + \theta_{error} \hat{v}_{ijc} + \epsilon_{ijc} \) where \( Z \) is the vector \((1, w, dist_{ic}, X_{jc}, A_{ijc})\) and \( \hat{v}_{ijc} \) is the residuals from first stage regression. Significance levels are denoted by * for \( p<0.1 \), ** for \( p<0.05 \) and *** for \( p<0.01 \). The row "df" reports the degree of freedom. For city control, we take into account the elevation, average rain fall, average temperature in Jan 01 and average temperature in July 01 for period 1995-2010. The observations are all annuli of all cities covered by both GMES and Corine Land Cover 1990. Other variables are those from original regression (GDP per capita at purchasing power standard and distance to CBD). Regression (1) to (4) are corresponding to IV regression (5) to (8) in Table 5 in the main text respectively.
### Table A.2: Hyperbolic - First stage regression and Wu-Hausman test for endogeneity

#### First stage regression

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Share of green area in GMES 2006</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Adjusted Share of green in 1990</td>
<td>0.804***</td>
<td>0.796***</td>
<td>0.793***</td>
<td>0.792***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.027)</td>
<td>(0.027)</td>
<td>(0.027)</td>
<td>(0.027)</td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.758</td>
<td>0.781</td>
<td>0.783</td>
<td>0.784</td>
<td></td>
</tr>
</tbody>
</table>

#### Wu-Hausman test for endogeneity

<table>
<thead>
<tr>
<th></th>
<th>Dependent variable:</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inverse of Space</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>( \hat{v}_{error} )</td>
<td>2.007</td>
<td>−0.626</td>
<td>−0.598</td>
<td>−0.526</td>
</tr>
<tr>
<td></td>
<td>(1.904)</td>
<td>(0.844)</td>
<td>(0.776)</td>
<td>(0.720)</td>
</tr>
</tbody>
</table>

| Country FE          | No       | Yes | Yes | Yes |
| City Geographical Controls | No       | No  | Yes | Yes |
| Annuili Amenity Controls | No      | No  | No  | Yes |
| Sample              | All      | All | All | All |
| Observations        | 10,853   | 10,853 | 10,853 | 10,853 |

**Note:** We using the following procedure to test for endogeneity. First Stage: \( g_{ijc} = \alpha g_{Corine90} + \theta'Z + \nu_{ijc} \). Second Stage: \( 1/s_{ijc} = \theta Z + \theta g_{ijc} + \theta_{err} \hat{v}_{ijc} + \epsilon_{ijc} \), where \( Z \) is the vector \( (1, w, \text{dist}, I_c, X_{jc}, A_{ijc}) \) and \( \hat{v}_{ijc} \) is the residuals from first stage regression. Significance levels are denoted by * for \( p<0.1 \), ** for \( p<0.05 \) and *** for \( p<0.01 \). The row "df" reports the degree of freedom. For city control, we take into account the elevation, average rain fall, average temperature in Jan 01 and average temperature in July 01 for period 1995-2010. The observations are all annulus from all cities covered by both GMES and Corine Land Cover 1990. Other variables are those from original regression (GDP per capita at purchasing power standard and distance to CBD). Regression (1) to (4) are corresponding to IV regression (5) to (8) in Table 5 in the main text respectively.
Appendix B  Counterfactual analysis

B.1 Willingness to pay

We denote the indirect utility function as $V(y,a,R) = \max_{z,s} U(z,s,a)$ s.t. $z + Rs \leq y = w - t$. Within the city boundaries, the equilibrium land rent is equal to the bid rent: $R = \hat{\psi}$. Replacing this into the indirect utility in equation (??), we obtain the willingness to pay $WTP$ that keeps the same utility level across the baseline and counterfactual profiles of net income $y$, green amenity $a$ and land rent $R$. In a closed city, this implies $V(y-WTP,a_1,R_1) = V(y,a_0,R_0)$ where the superscripts $0$ and $1$ refer to the baseline and the counterfactual scenarios.

B.1.1 Cobb Douglas model

For Cobb-Douglas model, the indirect utility function is computed as $V = (\phi \kappa) \phi y^{1-\psi} R^{-\phi} e^{\phi a}$ and the equilibrium land rent as $R = \kappa (uy^{-(1-\varphi)}e^{-\varphi a})^{-\frac{1}{\psi}}$ where $\kappa = (1-\varphi)^{-\frac{1-\varphi}{\psi}} (1 - \varphi - \phi)^{\frac{1-\varphi-\phi}{\phi}}$.

The willingness to pay is therefore given by $WTP = y \left[1 - e^{\varphi \left(1 - a_0 - a_1\right)} \left(\frac{R_0}{R_1}\right)^{-\frac{1}{\psi}}\right]$. Using land rents, the equilibrium willingness to pay is finally equal to $WTP = y \left[1 - (\frac{u^0}{u^1})^{\frac{1}{1-\varphi}}\right]$ where $u^0$ is the equilibrium in the baseline equilibrium and $u^1$ is the new equilibrium utility determined by the population constraint condition.

In the closed city, the new equilibrium utility depends on whether the new policy involves the conversion of urban green land into residential land. Suppose that the new green amenity level $a_1$ requires a smaller fraction of land devoted for urban green $g_1 < g_0$, and the freed land is $(g_0 - g_1) \ell$. If there is no conversion policy, the new utility equilibrium is given by

$$u_{\text{no conversion}}^1 = u^0 \left( \frac{\int_0^{y^0} \frac{1-g^0}{(y-(1-\phi-\varphi)e^{-\varphi a})^{\frac{1}{\psi}}} \ell dr}{\int_0^{y^0} \frac{1-g^0}{(y-(1-\phi-\varphi)e^{-\varphi a})^{\frac{1}{\psi}}} \ell dr} \right)^\phi.$$

If the freed land $(g^0 - g^1) \ell$ is converted in residential land, we can compute the new equilib-
rium utility as below:

\[
    u_{\text{conversion}}^1 = u^0 \left( \frac{\int_0^{\phi^0} \frac{1-g^1}{(y-(1-\phi-\varphi)e^{-\varphi a^1})^\phi} \ell dr}{\int_0^{\phi^0} \frac{1-g^0}{(y-(1-\phi-\varphi)e^{-\varphi a^0})^\phi} \ell dr} \right)^\phi.
\]

Since \( y, \ell, g^0, a^0, g^1 \) and \( a^1 \) are functions of \( r \), those expressions cannot be simplified. A numerical estimation is justified.

**B.1.2 Hyperbolic model**

In the hyperbolic model the indirect utility function writes as \( V = y - \sqrt{2\theta R} + a \) and the equilibrium land rent as \( R = \frac{1}{2\theta} (y + a - u)^2 \). The willingness to pay is then given by \( WTP = (a^1 - a^0) - \sqrt{2\theta} (\sqrt{R^1} - \sqrt{R^0}) \) or after plugging the equilibrium land rent \( WTP = u^1 - u^0 \).

In closed cities, the new equilibrium utility \( u^1 \) is determined by the population constraint condition. If there is no land conversion, the new utility equilibrium is given by

\[
    u_{\text{no conversion}}^1 = u^0 + \left( \frac{\int_0^{\phi^0} (1-g^0)(a^1 - a^0) \ell dr}{\int_0^{\phi^0} (1 - g^1) \ell dr} \right).
\]

After land conversion, it is equal to

\[
    u_{\text{conversion}}^1 = u^0 \left( \frac{\int_0^{\phi^0} (1-g^0) \ell dr}{\int_0^{\phi^0} (1 - g^1) \ell dr} \right) + \left( \frac{\int_0^{\phi^0} (1 - g^1)(y + a^1) \ell dr - \int_0^{\phi^0} (1-g^0)(y + a^0) \ell dr}{\int_0^{\phi^0} (1 - g^1) \ell dr} \right).
\]

Since \( y, \ell, g^0, a^0, g^1 \) and \( a^1 \) are functions of \( r \), those expressions cannot be simplified. A numerical estimation is justified.
B.2 Recovering parameters

B.2.1 Cobb-Douglas preferences

We recover the model parameters from the estimated coefficient of residents’ land use using the values of $\vartheta_0$, $\vartheta_1$, $\vartheta_2$, $\vartheta_3$ and $\vartheta_4$ from Column (8) in Table 5. Country utility levels are recovered from the parameters $\vartheta_5^c$ and the constant term $\vartheta_0$\footnote{As we drop Austria in the country dummies, we have $u_{i,t}^{1/\phi} = \vartheta_0$, and all other countries as $u_c^{1/\phi} = \vartheta_5^c + \vartheta_0$}. From the theoretical model, we recover the residential space, composite goods and the residential land rent as

$$\hat{s}(w, r, g, u, \varepsilon) = (we^{-\hat{\tau}_1 r - \hat{\tau}_2 r^2})^{\hat{\vartheta}_1} u e^{\hat{\vartheta}_4 X_{jc} + \hat{\vartheta}_6 A_{ijc} + \hat{\varepsilon}_{ijc}}$$

$$\hat{z}(w, r) = we^{-\hat{\tau}_1 r - \hat{\tau}_2 r^2} \left( \frac{-\hat{\vartheta}_1}{1 - \hat{\vartheta}_1} \right)$$

$$\hat{R}(w, r, g, u, \varepsilon) = \frac{we^{-\hat{\tau}_1 r - \hat{\tau}_2 r^2} - \hat{z}(w, r)}{\hat{s}(w, r, g, u, X, \varepsilon)}$$

where we use $\hat{\vartheta}_1 = \hat{\vartheta}_2 / \hat{\vartheta}_1$, $\hat{\tau}_2 = \hat{\vartheta}_3 / \hat{\vartheta}_1$, and $(1 - \hat{\varphi} - \hat{\hat{\varphi}})/(1 - \hat{\varphi}) = -\hat{\vartheta}_1/(1 - \hat{\vartheta}_1)$.

B.2.2 Hyperbolic preferences

Similarly, we have the following functions for residential space $s$, composite good $z$ and the residential land rent $R$ for hyperbolic preferences.

$$\hat{s}(w, r, g, u, \varepsilon) = \frac{\hat{\theta}}{w - w(\hat{\tau}_1 r + \hat{\tau}_2 r^2) + \frac{a}{\beta} - u_c + \hat{\vartheta}_5 X_{jc} + \hat{\vartheta}_6 A_{ijc} + \hat{\varepsilon}_{ijc}}$$

$$\hat{z}(w, r, g, u, \varepsilon) = \frac{w - w(\hat{\tau}_1 r + \hat{\tau}_2 r^2) - \frac{a}{\beta} + u_c - \hat{\vartheta}_5 X_{jc} - \hat{\vartheta}_6 A_{ijc} - \hat{\varepsilon}_{ijc}}{2}$$

$$\hat{R}(w, r, g, u, \varepsilon) = \frac{w - w(\hat{\tau}_1 r + \hat{\tau}_2 r^2) - \hat{z}(w, r, g, u, \varepsilon)}{\hat{s}(w, r, g, u, \varepsilon)}$$

where $\hat{\theta} = 1/\hat{\vartheta}_1$, $\hat{\tau}_1 = -\hat{\vartheta}_2 / \hat{\vartheta}_1$, $\hat{\tau}_2 = -\hat{\vartheta}_3 / \hat{\vartheta}_1$, and $\hat{\beta} = \hat{\vartheta}_1 / \hat{\vartheta}_4$. 

\footnote{As we drop Austria in the country dummies, we have $u_{i,t}^{1/\phi} = \vartheta_0$, and all other countries as $u_c^{1/\phi} = \vartheta_5^c + \vartheta_0$}
B.3 Counterfactual exercises – detailed steps

We first define the baseline model and the counterfactual exercises. Both baseline and counterfactuals use the observed distance to the city center $r_{ijc}$ and amenities $X_{jc}$ and $A_{jc}$. The baseline model includes the observed city wage $w_{jc}$, the share of green urban areas $g_{ijc}$, the estimated values of country utility $\hat{u}_c$ and the unobserved heterogeneity or measurement error $\hat{\varepsilon}_{ijc}$. Formally, we set the baseline model values to $s_{ijc}^0 = \hat{s}(w_{jc}, r_{ijc}, g_{ijc}, \hat{u}_c, \hat{\varepsilon}_{ijc})$, $z_{ijc}^0 = \hat{z}(w_{jc}, r_{ijc})$ and $R_{ijc}^0 = \hat{R}(w_{jc}, r_{ijc}, g_{ijc}, \hat{u}_c, \hat{\varepsilon}_{ijc})$.

We now investigate the impact of canceling 50% of the green urban areas in each annulus. In counterfactual exercise 1, we consider open cities where utility levels and unobserved heterogeneity are maintained at the estimated levels $\hat{u}_c$ and $\hat{\varepsilon}_{ijc}$. We then remove half of the green urban areas by setting $g'_{ijc} = 0.5 \times g_{ijc}$. We set $s_{ijc}^1 = \hat{s}(w_{jc}, r_{ijc}, g'_{ijc}, \hat{u}_c, \hat{\varepsilon}_{ijc})$ and $z_{ijc}^1 = \hat{z}(w_{jc}, r_{ijc})$, while $R_{ijc}^1 = \hat{R}(w_{jc}, r_{ijc}, g'_{ijc}, \hat{u}_c, \hat{\varepsilon}_{ijc})$. Residents’ land use should increase ($s_{ijc}^1 > s_{ijc}^0$) because residents require compensation for the reduction of green area amenities. If green urban areas are left with no use, the total available space remains constant and is given by $\sum_{ijc} (1 - g_{ijc}) \ell_{ijc}$, where $\ell_{ijc}$ is the land surface of annulus $i$ in city $j$ and country $c$. Since resident’s land use increases, cities host fewer residents. If green urban areas are converted in residential land, city populations may grow if the new supply of land, $g'_{ijc} \ell_{ijc}$, is larger than the increase in residents’ land demand from $s_{ijc}^0$ to $s_{ijc}^1$. More formally, population grows if $\sum_{ijc} (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0 < \sum_{ijc} (1 - g'_{ijc}) \ell_{ijc} / s_{ijc}^1$.

In counterfactual exercise 2, we consider closed cities with exogenous city populations and remove half of the green urban areas ($g'_{ijc} = 0.5 \times g_{ijc}$). We set $s_{ijc}^2 = \hat{s}(w_{jc}, r_{ijc}, g'_{ijc}, u_{jc}, \hat{\varepsilon}_{ijc})$, $z_{ijc}^2 = \hat{z}(w_{jc}, r_{ijc})$ and $R_{ijc}^2 = \hat{R}(w_{jc}, r_{ijc}, g'_{ijc}, u_{jc}, \hat{\varepsilon}_{ijc})$, where $u_{jc}$ is the counterfactual city utility level. In the absence of the conversion of green urban areas to residential plots, we set the city utility level $u_{jc}^2$ such that the city population spreads over the baseline residential area; that is, we impose that each $u_{jc}^2$ solves the population identity $\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0 = \sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2$. In the case of land conversion, we set $u_{jc}^2$ such that the city population spreads over the new residential land supply. Then, $u_{jc}^2$ solves the population identity $\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0 = \sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2$. However, although utility levels are important concepts in welfare analysis, they are difficult to interpret quantitatively. Therefore, we also compute the compensating variation wage $w_{jc}^2$ as the city wage that maintains the baseline utility.

\[ (u_{jc}^2)_{1/\phi} = (u_c)_{1/\phi} \left( \frac{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2}{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0} \right) \]

\[ (u_{jc}^2)_{1/\phi} = (u_c)_{1/\phi} \left( \frac{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2}{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0} \right) \]

\[ (u_{jc}^2)_{1/\phi} = (u_c)_{1/\phi} \left( \frac{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2}{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0} \right) \]

\[ (u_{jc}^2)_{1/\phi} = (u_c)_{1/\phi} \left( \frac{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^2}{\sum_i (1 - g_{ijc}) \ell_{ijc} / s_{ijc}^0} \right) \]
level when we remove green urban areas, which is equivalent to setting the wage \( w_{j}^{2} \) such that the above population identities hold with \( \hat{s}(w_{j}^{2}, r_{ijc}, g_{ijc}, u_{jc}, \hat{\varepsilon}_{ijc}) \). Under the Cobb-Douglas preferences, this assumption simplifies to the compensating variation wage \( w_{j}^{2} = w_{jc}(u_{jc}^{2}/u_{jc}^{0})^{1/\hat{\gamma}_{1}} \).

The above two counterfactual exercises hinge on the assumption that empirical model residuals \( \varepsilon_{ijc} \) reflect land heterogeneity that is unobserved to the econometricians but observed and used by residents in their land plot size choices. Such heterogeneity is reported in the counterfactual results. This assumption may be strong, as it imposes strong information on behalf of residents. The opposite view assumes that the residuals \( \varepsilon_{ijc} \) consist of measurement errors that can be observed neither by the econometricians nor the residents. In that case, residents do not base their decisions on \( \varepsilon_{ijc} \) so that we must set \( \varepsilon_{ijc} = 0 \) in counterfactual exercises. A discussion of these two approaches is briefly given around Table 4. Since those exercises yield very close results, the second approach are not reported in the analysis.

### Appendix C  Robustness check for Cobb-Douglas preferences with NUTS3 incomes

In this section, we report the results of estimation of the structural model using GDP per capita at NUTS3 level as the proxy for city wage. The results are similar to those in Table 2 in the main text.
Table C.1: Regression Results using GDP per capita at NUTS3 as proxy for city’s wage level

<table>
<thead>
<tr>
<th></th>
<th>OLS</th>
<th></th>
<th>IV</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>Constant</td>
<td>−0.686***</td>
<td>−0.899***</td>
<td>−0.834*</td>
<td>−0.230</td>
</tr>
<tr>
<td></td>
<td>(0.119)</td>
<td>(0.256)</td>
<td>(0.467)</td>
<td>(0.425)</td>
</tr>
<tr>
<td>Ln Household Income</td>
<td>−0.211***</td>
<td>−0.614***</td>
<td>−0.608***</td>
<td>−0.542***</td>
</tr>
<tr>
<td></td>
<td>(0.077)</td>
<td>(0.103)</td>
<td>(0.098)</td>
<td>(0.090)</td>
</tr>
<tr>
<td>Dist. to CBD</td>
<td>1.596***</td>
<td>1.482***</td>
<td>1.514***</td>
<td>1.004***</td>
</tr>
<tr>
<td></td>
<td>(0.239)</td>
<td>(0.220)</td>
<td>(0.212)</td>
<td>(0.219)</td>
</tr>
<tr>
<td>Dist. to CBD square</td>
<td>−0.610***</td>
<td>−0.515***</td>
<td>−0.518***</td>
<td>−0.322**</td>
</tr>
<tr>
<td></td>
<td>(0.134)</td>
<td>(0.146)</td>
<td>(0.149)</td>
<td>(0.142)</td>
</tr>
<tr>
<td>Share of Urban Green</td>
<td>−2.045***</td>
<td>−1.773***</td>
<td>−1.681***</td>
<td>−1.487***</td>
</tr>
<tr>
<td></td>
<td>(0.386)</td>
<td>(0.245)</td>
<td>(0.241)</td>
<td>(0.203)</td>
</tr>
<tr>
<td>Country FE</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Geographical Controls</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Annuili Amenity Controls</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Sample</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
</tbody>
</table>

|                  | (5) | (6)                      | (7) | (8)                      |
| Constant         | −0.682*** | −0.880***        | −0.808* | −0.213             |
|                  | (0.119) | (0.262)                | (0.473) | (0.430)               |
| Ln Household Income | −0.211*** | −0.610***          | −0.604*** | −0.540***            |
|                  | (0.077) | (0.103)                | (0.098) | (0.090)               |
| Dist. to CBD     | 1.591*** | 1.475***              | 1.509*** | 0.998***             |
|                  | (0.240) | (0.221)                | (0.213) | (0.220)               |
| Dist. to CBD square | −0.608*** | −0.512***          | −0.517*** | −0.320**            |
|                  | (0.133) | (0.146)                | (0.148) | (0.140)               |
| Share of Urban Green | −2.079*** | −1.948***         | −1.851*** | −1.611***            |
|                  | (0.413) | (0.274)                | (0.262) | (0.228)               |

|                  | (9) | (10)                     | (11) | (12)                     |
| Constant         | −0.682*** | −0.880***        | −0.808* | −0.213             |
|                  | (0.119) | (0.262)                | (0.473) | (0.430)               |
| Ln Household Income | −0.211*** | −0.610***          | −0.604*** | −0.540***            |
|                  | (0.077) | (0.103)                | (0.098) | (0.090)               |
| Dist. to CBD     | 1.591*** | 1.475***              | 1.509*** | 0.998***             |
|                  | (0.240) | (0.221)                | (0.213) | (0.220)               |
| Dist. to CBD square | −0.608*** | −0.512***          | −0.517*** | −0.320**            |
|                  | (0.133) | (0.146)                | (0.148) | (0.140)               |
| Share of Urban Green | −2.079*** | −1.948***         | −1.851*** | −1.611***            |
|                  | (0.413) | (0.274)                | (0.262) | (0.228)               |

Note: Significance levels are denoted by * for p<0.1, ** for p<0.05 and *** for p<0.01. Standard errors are clustered at city level. The row "df" reports the degree of freedom. Here, we use the GDP per capita taken from Regional Economic Accounts from Eurostat at NUTS3 level with adjustment to purchasing power standard (PPS) as the proxy for city income level, and it is measured in €100,000. The distance to CBD is measured in 10 kilometres. The inverse of space is calculated by divided number of inhabitants in each annuli with the areas within the annuli minus the areas using as urban green (in 100 meters). We exclude Cyprus and Luxembourg as the Eurostat population grid database does not cover Cyprus and the household income data at NUTS2 of Eurostat does not cover Luxembourg. United Kingdom and Finland are also excluded as they are not covered by Corine Land Cover 1990. City boundary is chosen at 20% cut-off point. For city control, we take into account the elevation, average rain fall, average temperature in Jan 01 and average temperature in July 01 for period 1995-2010. City amenity controls include the share of industrial, sport and leisure land use as well as the share of forest and agriculture land within 100 meters buffer from residential area.
### Table C.2: First stage regression and Wu-Hausman test for endogeneity

#### First stage regression

<table>
<thead>
<tr>
<th>Dependent variable: Share of green area in GMES 2006</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adjusted Share of green area in Corine 1990</td>
<td>0.797***</td>
<td>0.793***</td>
<td>0.790***</td>
<td>0.789***</td>
</tr>
<tr>
<td></td>
<td>(0.028)</td>
<td>(0.027)</td>
<td>(0.027)</td>
<td>(0.027)</td>
</tr>
</tbody>
</table>

#### Wu-Hausman test for endogeneity

<table>
<thead>
<tr>
<th>Dependent variable: Ln Residential Space</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \hat{e}_{\text{error}} )</td>
<td>-0.330</td>
<td>0.413</td>
<td>0.406</td>
<td>0.241</td>
</tr>
<tr>
<td></td>
<td>(0.911)</td>
<td>(0.455)</td>
<td>(0.438)</td>
<td>(0.407)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Country FE</th>
<th>No</th>
<th>Yes</th>
<th>Yes</th>
<th>Yes</th>
</tr>
</thead>
<tbody>
<tr>
<td>City Geographical Controls</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Annuilli Amenity Controls</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Sample</td>
<td>All</td>
<td>All</td>
<td>All</td>
<td>All</td>
</tr>
<tr>
<td>Observations</td>
<td>10,853</td>
<td>10,853</td>
<td>10,853</td>
<td>10,853</td>
</tr>
</tbody>
</table>

**Note:** We using the following procedure to test for endogeneity. First Stage: \( g_{ijc} = \alpha g_{\text{Corine90}} + \vartheta Z + \nu_{ijc} \); Second Stage: \( \ln s_{ijc} = \vartheta Z + \vartheta_3 \ln (g_0 + g_{ijc}) + \vartheta_{\text{error}} \nu_{ijc} + \epsilon_{ijc} \) where Z is the vector \((1 \ w \ dist \ I_c \ X_{jc})\) and \( \nu_{ijc} \) is the residuals from first stage regression. Significance levels are denoted by \(*\) for \( p<0.1\), \(**\) for \( p<0.05\) and \( ***\) for \( p<0.01\). The row "df" reports the degree of freedom. For city control, we take into account the elevation, average rain fall, average temperature in Jul 01 and average temperature in Jul 01 for period 1995-2010. The observations are all annulus from all cities covered by both GMES and Corine Land Cover 1990. Other variables are those from original regression (GDP per capita at purchasing power standard and distance to CBD). Regression (1) to (4) are corresponding to IV regression (5) to (8) in Table A1 respectively.

### Table C.3: Counterfactual analysis: open and closed cities

<table>
<thead>
<tr>
<th>Cities number</th>
<th>Composite Goods (Z) ((\text{e1000}))</th>
<th>Housing Rent ((R \times s)) ((\text{e1000}))</th>
<th>Income Area ((W)) ((\text{e1000}))</th>
<th>Residential Area ((\text{km}^2))</th>
<th>Green Area ((\text{GA})) ((\text{km}^2))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spatial heterogeneity</td>
<td>264</td>
<td>6.39</td>
<td>11.84</td>
<td>26.55</td>
<td>25.29</td>
</tr>
<tr>
<td></td>
<td>(3.01)</td>
<td>(5.58)</td>
<td>(13.51)</td>
<td>(48.91)</td>
<td>(9.87)</td>
</tr>
<tr>
<td>No spatial heterogeneity</td>
<td>264</td>
<td>5.03</td>
<td>6.35</td>
<td>11.76</td>
<td>26.55</td>
</tr>
<tr>
<td></td>
<td>(2.99)</td>
<td>(5.55)</td>
<td>(13.51)</td>
<td>(48.91)</td>
<td>(9.87)</td>
</tr>
</tbody>
</table>

**Note:** The standard deviation is reported in the parenthesis. Household income is taken from Eurostat at NUTS2 level and is measured on purchasing power standard (PPS) at 1000€. More details on PPS measure, please check Eurostat technical documents.
Table C.4: City structure under closed and open scenarios $g = 0.5 \times g_0$

<table>
<thead>
<tr>
<th>Cities (number)</th>
<th>$s$ (100m$^2$/hab)</th>
<th>Land Rent (€/$m^2$/y)</th>
<th>Green value (€/$m^2$/y)</th>
<th>Pop. ($\hat{u}$) (mil.)</th>
<th>$U/\bar{U}$ Comp. $W$ (€/1000)</th>
<th>Total loss in housing market (€ mil.)</th>
<th>Total loss in wage comp. (€ mil.)</th>
<th>Population 1,000 hab.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Baseline 0 (with heterogeneity)</strong></td>
<td>264</td>
<td>0.95</td>
<td>161.88</td>
<td>147.25</td>
<td>0.31</td>
<td>1.60</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>(0.44)</td>
<td>(127.49)</td>
<td>(140.65)</td>
<td>(0.69)</td>
<td>(0.33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$g = 0.5 \times g_0$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Counterfactual 1: Open City</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban green conversion</td>
<td>No</td>
<td>264</td>
<td>1.00</td>
<td>152.18</td>
<td>162.30</td>
<td>0.29</td>
<td>1.00</td>
<td>228.36</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>264</td>
<td>0.99</td>
<td>153.16</td>
<td>162.30</td>
<td>0.32</td>
<td>1.00</td>
<td>−131.58</td>
</tr>
<tr>
<td></td>
<td>(0.46)</td>
<td>(118.02)</td>
<td>(124.64)</td>
<td>(0.65)</td>
<td>(0.33)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(0.46)</td>
<td>(119.03)</td>
<td>(124.64)</td>
<td>(0.71)</td>
<td>(0.33)</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Counterfactual 2: Closed City</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Urban green conversion</td>
<td>No</td>
<td>264</td>
<td>0.95</td>
<td>161.78</td>
<td>172.54</td>
<td>0.31</td>
<td>0.95</td>
<td>29.56</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>264</td>
<td>1.03</td>
<td>145.86</td>
<td>154.38</td>
<td>0.31</td>
<td>1.04</td>
<td>24.58</td>
</tr>
<tr>
<td></td>
<td>(0.47)</td>
<td>(111.58)</td>
<td>(115.64)</td>
<td>(0.69)</td>
<td>(0.34)</td>
<td>(12.62)</td>
<td>(56.06)</td>
<td>(2,420.57)</td>
</tr>
<tr>
<td><strong>Baseline 0 (without heterogeneity)</strong></td>
<td>264</td>
<td>0.89</td>
<td>163.66</td>
<td>175.17</td>
<td>0.28</td>
<td>1.00</td>
<td></td>
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<td>(0.37)</td>
<td>(122.22)</td>
<td>(127.79)</td>
<td>(0.50)</td>
<td>(0.33)</td>
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<tr>
<td>$g = 0.5 \times g_0$</td>
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<td></td>
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<td><strong>Counterfactual 3: Open City</strong></td>
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</tr>
<tr>
<td>Urban Green Conversion</td>
<td>No</td>
<td>264</td>
<td>0.94</td>
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<td>160.68</td>
<td>0.27</td>
<td>1.00</td>
<td>204.58</td>
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<tr>
<td></td>
<td>Yes</td>
<td>264</td>
<td>0.94</td>
<td>154.12</td>
<td>160.68</td>
<td>0.29</td>
<td>1.00</td>
<td>−112.14</td>
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<tr>
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<td>(0.38)</td>
<td>(112.88)</td>
<td>(114.27)</td>
<td>(0.50)</td>
<td>(0.33)</td>
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<td></td>
<td>(0.38)</td>
<td>(112.85)</td>
<td>(114.27)</td>
<td>(0.55)</td>
<td>(0.33)</td>
<td></td>
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<tr>
<td><strong>Counterfactual 4: Closed City</strong></td>
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</tr>
<tr>
<td>Urban Green Conversion</td>
<td>No</td>
<td>264</td>
<td>0.89</td>
<td>163.54</td>
<td>170.64</td>
<td>0.28</td>
<td>0.95</td>
<td>16.65</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>264</td>
<td>0.97</td>
<td>147.30</td>
<td>153.74</td>
<td>0.28</td>
<td>1.04</td>
<td>14.61</td>
</tr>
<tr>
<td></td>
<td>(0.37)</td>
<td>(122.30)</td>
<td>(123.46)</td>
<td>(0.53)</td>
<td>(0.31)</td>
<td>(6.47)</td>
<td>(33.94)</td>
<td>(4,167.02)</td>
</tr>
<tr>
<td></td>
<td>(0.39)</td>
<td>(106.09)</td>
<td>(107.66)</td>
<td>(0.53)</td>
<td>(0.34)</td>
<td>(5.70)</td>
<td>(35.75)</td>
<td>(2,123.28)</td>
</tr>
</tbody>
</table>

Note: The standard deviation is reported in the parenthesis. Household income is taken from Eurostat at NUTS2 level and is measured on purchasing power standard (PPS) at 1000€. More details on PPS measure, please check Eurostat technical documents. Population is calculated in million inhabitants. Utility is measured relatively with baseline average. Basically, we measure

$$\bar{U}_{jc} = \frac{1}{N} \sum_{j=1}^{N} u_{jc}$$

where $u_{jc}$ is calculated as in above section.
Table C.5: Quantiles analysis: between- and within-city statistics

<table>
<thead>
<tr>
<th>Baseline wage (€1000/hab/y)</th>
<th>Between cities</th>
<th>City Income Quartiles</th>
<th>0-0.25</th>
<th>0.25-0.50</th>
<th>0.50-0.75</th>
<th>0.75-1</th>
<th>0-0.25</th>
<th>0.25-0.50</th>
<th>0.50-0.75</th>
<th>0.75-1</th>
<th>0-0.25</th>
<th>0.25-0.50</th>
<th>0.50-0.75</th>
<th>0.75-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>City Size Quartiles</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Distance to CBD Quartiles</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
<td>0-0.25</td>
<td>0.25-0.50</td>
<td>0.50-0.75</td>
<td>0.75-1</td>
</tr>
<tr>
<td>Increase in comp var wage(€1000/hab/y)</td>
<td>Counterfactual 1: Open City</td>
<td>Urban green conversion</td>
<td>No</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>–0.83</td>
<td>–1.59</td>
<td>–2.06</td>
<td>–3.40</td>
<td>–2.12</td>
<td>–1.96</td>
<td>–1.60</td>
<td>–2.21</td>
<td>–1.20</td>
<td>–1.66</td>
<td>–1.94</td>
<td>–2.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.09)</td>
<td>(1.43)</td>
<td>(1.63)</td>
<td>(2.91)</td>
<td>(2.74)</td>
<td>(1.99)</td>
<td>(1.25)</td>
<td>(1.73)</td>
<td>(2.47)</td>
<td>(2.01)</td>
<td>(1.99)</td>
<td>(2.96)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Counterfactual 2: Closed City</td>
<td>Urban green conversion</td>
<td>No</td>
<td>1.38</td>
<td>2.15</td>
<td>3.08</td>
<td>5.42</td>
<td>2.48</td>
<td>2.86</td>
<td>2.71</td>
<td>3.96</td>
<td>3.54</td>
<td>4.15</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Yes</td>
<td>–0.83</td>
<td>–1.59</td>
<td>–2.06</td>
<td>–3.40</td>
<td>–2.12</td>
<td>–1.96</td>
<td>–1.60</td>
<td>–2.21</td>
<td>–1.20</td>
<td>–1.66</td>
<td>–1.94</td>
<td>–2.59</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(1.79)</td>
<td>(1.32)</td>
<td>(1.69)</td>
<td>(2.82)</td>
<td>(2.66)</td>
<td>(2.34)</td>
<td>(1.74)</td>
<td>(2.87)</td>
<td>(4.24)</td>
<td>(3.97)</td>
<td>(3.08)</td>
<td>(2.50)</td>
<td></td>
</tr>
<tr>
<td>Land rent baseline (€/m²/y)</td>
<td>Counterfactual 1: Open City</td>
<td>Urban green conversion</td>
<td>No</td>
<td>4.10</td>
<td>8.25</td>
<td>10.66</td>
<td>15.80</td>
<td>8.14</td>
<td>8.79</td>
<td>9.65</td>
<td>12.22</td>
<td>19.43</td>
<td>13.57</td>
<td>7.66</td>
</tr>
<tr>
<td></td>
<td>Counterfactual 2: Closed City</td>
<td>Urban green conversion</td>
<td>No</td>
<td>0.12</td>
<td>0.14</td>
<td>0.10</td>
<td>0.05</td>
<td>0.00</td>
<td>0.03</td>
<td>0.15</td>
<td>0.23</td>
<td>–0.16</td>
<td>1.99</td>
<td>–0.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7.50)</td>
<td>(11.91)</td>
<td>(21.07)</td>
<td>(30.11)</td>
<td>(26.76)</td>
<td>(15.05)</td>
<td>(19.48)</td>
<td>(20.69)</td>
<td>(37.99)</td>
<td>(23.90)</td>
<td>(18.68)</td>
<td>(27.27)</td>
<td></td>
</tr>
</tbody>
</table>

Note: The standard deviations are reported in the parentheses. Here, we report only the case with heterogeneity; for non-heterogeneity case (like in counterfactual exercises 3 and 4), the results are similar. The loss for landlord is accounted as the difference between new land rent equilibrium and land rent in baseline model 0.