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Causes and Consequences of Open Space in U.S. Urban Areas

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ENVIRONMENT DIRECTORATE

**CAUSES AND CONSEQUENCES OF OPEN SPACE IN U.S. URBAN AREAS - ENVIRONMENT
WORKING PAPER No. 112**

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ABSTRACT

The provision of open space is at the heart of a complex arbitration of local public finance and urban quality of life. The amount of open space varies substantially across urban areas. This variation raises some natural questions: What determines the amount of open space in an urban area? How does the amount of open space affect housing prices and local tax revenues? How can we assess whether the amount of open space in urban areas is socially optimal? This paper conducts theoretical and empirical analysis to address these issues. The theoretical analysis reveals that price elasticities of housing demand and supply, economies of scale in providing public services, and capitalized and non-capitalized values of environmental benefits from open space are key parameters affecting the optimal amount of open space. The effects of these parameters are tested on the basis of a sample of U.S. urban areas. Empirical results suggest that a significant share of U.S. urban areas has too little open space, in the sense that additional open space conservation could increase land values and social welfare.

Keywords: Open space conservation; land values; environmental amenities; local public finances

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RÉSUMÉ

L'offre des espaces ouverts en milieu urbain est au cœur d'un complexe arbitrage entre les finances publiques locales et la qualité de la vie. Les surfaces dédiées aux espaces ouverts varient considérablement à travers les aires urbaines. Cette variabilité soulève naturellement plusieurs questions : quels sont les déterminants de cette offre ? Comment la mise en place des espaces verts affecte les prix des logements et les recettes fiscales locales ? Comment peut-on évaluer si l'offre des espaces verts est socialement optimale ? Ce papier conduit des analyses théorique et empirique pour répondre à ces questions. L'analyse théorique révèle que les élasticités prix de l'offre et de demande des logements, les économies d'échelle liées aux services publics, ainsi que les valeurs, capitalisée ou non, des bénéfices environnementaux sont les facteurs clés pour déterminer le niveau optimal des espaces ouverts. Les effets de ces paramètres ont été empiriquement testés sur la base d'un échantillon d'aires urbaines américaines. Les résultats empiriques suggèrent qu'une part significative des aires urbaines américaine dispose de peu d'espaces ouverts. Ainsi une offre supplémentaire peut accroître la valeur des terres et le bien-être social.

Mots-clés: Conservation des espaces ouverts ; valeurs de la terre ; aménités environnementales ; finances publiques locales

Classification JEL: H4; R3; Q2

FOREWORD

This report has been authored by JunJie Wu (Oregon State University), Walid Oueslati (OECD, Environment Directorate) and Jialing Yu (Oregon State University). The authors are grateful to delegates to the Working Party on Integrating Environmental and Economic Policies for helpful comments on earlier drafts of this paper. They would also like to thank Shardul Agrawala, Alexandros Dimitropoulos, Abel Schumann, Valentine Rinner and Ioannis Tikoudis for comments on previous versions of the paper, and Natasha Cline-Thomas for editorial assistance. The authors are responsible for any remaining omissions or errors. Work on this paper was conducted under the overall responsibility of Shardul Agrawala, Head of the Environment and Economy Integration Division.

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EXECUTIVE SUMMARY¹

Open space includes all unbuilt, agricultural and natural land within urban, suburban, and rural areas. It comprises both public lands such as city parks and stream corridors, and private lands such as rangelands, grasslands, farms, and ranches. Open space provides vital ecosystem services and public benefits to society. Examples of open space benefits abound. It reduces urban runoffs, protects water quality, moderates local climate, and provides wildlife habitat. It also provides recreational sites for urban dwellers, increases nearby property values, and generates municipal revenue through higher property tax assessments.

Open space conservation by public authorities does not, however, come without cost. In addition to acquisition and management costs, there are also opportunity costs related to government budget constraints. Money spent on open space conservation cannot be used to provide other public goods valued by local residents. If a local jurisdiction wants to conserve more open space without reducing other public spending, it may have to raise revenues from local taxes to cover the expenses. This can be challenging, especially considering that open space conservation is likely to reduce the tax base for local authorities, as land is set aside from residential, commercial or industrial development.

The provision of open space is thus at the heart of a complex arbitration of local public finance and urban quality of life. The amount of open space varies substantially across urban areas, even within a country. This large variation in the amount of open space raises some natural questions: What determines the amount of open space in an urban area? How does the amount of open space affect housing prices and local taxes? How can we assess whether the amount of open space in urban areas is socially optimal?

This paper aims to answer these questions. A theoretical model is first developed to identify the key factors determining the optimal amount of open space in an urban area. The model reveals the conditions under which open space can increase: (a) property tax rates, (b) public services, (c) total land values, and (d) social welfare. The findings from the theoretical model are empirically tested in an analysis of open space conservation in a large number of urban areas in the United States. The empirical analysis investigates the influence of various factors on the share of land devoted to open space conservation, and the impact of open space conservation on property tax rates and local public services. The analysis also assesses whether the amount of open space in U.S. urban areas in 2011 could be considered as socially optimal.

A number of important findings are drawn from the study. First, open space conservation increases the total value of land in the jurisdiction, if the demand and supply of housing are not too sensitive to changes in housing prices. Second, the effect of open space conservation on land value depends on the amount of land preserved – an adequate amount of open space is likely to increase the total land value, while too much open space conservation tends to have the opposite effect. Third, empirical results confirm that the price elasticity of housing supply is an important determinant of the amount of open space in U.S. urban areas (UAs). Although the demand for housing is relatively inelastic in many UAs, the supply elasticity varies significantly across them. Urban areas with less stringent land use regulation and lower population density tend to have higher price elasticities of housing supply. Other things being equal, these UAs tend to have a lower property tax rate, and possibly a smaller share of land in open space, and a higher

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per-capita spending on municipal services. In contrast, urban areas with stringent land use regulation and high population density generally have lower elasticities of housing supply.

Finally, empirical results suggest that a significant share of U.S. urban areas has too little open space, in the sense that additional open space conservation could increase total land values and social welfare as long as it does not generate disamenities. The share of such urban areas in the sample used here is 42%, according to the most conservative estimate, but could be as high as 50%, depending on the model and subsample used. However, for about 38% of the urban areas of the sample the total value of non-capitalised environmental benefits from open space must be at least as large as the total land value within the urban area to justify the amount of open space they have.

This study demonstrates that open space conservation is at the heart of a complex arbitration of forces influencing urban quality of life. Many factors determine the outcomes of this arbitration, including local housing market conditions, local geographic characteristics, local regulatory environments, and preferences and demographics of local residents. Although it may be challenging to determine the optimal amount of open space in an urban area, potential payoffs are likely high for each local jurisdiction to examine the existing amount, pattern, and types of open space and determine an appropriate short-term action plan and a long-term conservation strategy. This study provides an adaptable framework to guide local decision-making on open space conservation, explicitly taking into account public finance constraints. It is possible that local policy making doesn't always aim to achieve the objectives assumed in this study. Still, the framework provides a systematic way to analyse the trade-offs between open space conservation and the provision of other public services at the local level and identify the main economic, geographic and demographic factors that should be taken into account in relevant decision-making processes.

1. INTRODUCTION

Growing recognition of the economic and environmental benefits of open space has sparked waves of conservation initiatives at local and state levels in the United States. From 1998 to 2014, U.S. voters approved 1861 conservation initiatives in local and state referenda, providing more than 72 billion USD for open space conservation (The Trust for Public Land, 2015). The implementation of locally based, long-term open space conservation plans has been advocated as a “smart growth” strategy in the United States (U.S. Environmental Protection Agency, 2015). In Europe, open space conservation has been acknowledged as an important aspect of the European Union’s strategy for the urban environment and the European Landscape Convention is a Europe-wide instrument that deals specifically with open space conservation (Déjeant-Pons, 2006).

Open space includes all unbuilt, agricultural and natural land within urban, suburban, and rural areas. It comprises both public lands such as city parks and stream corridors, and private lands such as rangelands, grasslands, farms, and ranches. This paper focuses on open spaces in urban areas. Urban open space provides many environmental benefits and ecosystem services (USDA Forest Service, 2007). For example, it cools urban heat islands down, moderates local climate and provides recreational sites (Donovan and Butry 2010; USDA Forest Service, 2014). Native grasslands reduce water runoffs, protect water quality, control storm water, and provide wildlife habitat. Urban forests and green space filter air, water, sunlight and provide shelter to wild animals (USDA Forest Service, 2014). In many instances, environmental problems are less costly to address through open space conservation than through public spending. For instance, it might be less costly to conserve open space for the purposes of water quality improvement and flood prevention than to use tax revenue to construct relevant infrastructure, such as water filtration plants and storm sewers (State of New York Office of the State Comptroller, 2010).

Open space also provides economic and social benefits. For example, it may increase property values and municipal revenue through higher property tax assessments (Donovan and Butry, 2011; Stone et al., 2015; USDA Forest Service, 2014). Urban green space provides a place for people to socialise and play, reducing stress and benefiting the health of urban dwellers (Ulrich, 1984, 1993). For example, recent research suggests that more canopy cover is associated with higher birth weights (Donovan et al., 2011), and trees in the public right of way are associated with lower crime rates in Portland (Donovan and Prestemon, 2012). As urban areas expand, the importance of the benefits that urban open space provides, as well as the challenges to their conservation, will increase (USDA Forest Service, 2011).

Open space conservation also implies costs. In addition to upfront purchasing costs, local governments have to recurrently incur maintenance costs for open space conservation. Not all costs of open space conservation are, however, immediately obvious; in fact, implicit costs may be significant. Open space conservation may reduce the tax base for local authorities, as land is set aside from commercial or industrial development. It also imposes substantial opportunity costs; money spent on open space conservation cannot be used for other public goods valued by local residents (Wu, 2014).

This paper focuses on open space provision in U.S. urban areas (UAs). The large variation in the amount of open space conserved across U.S. UAs raises some natural questions: What determines the amount of open space in an urban area? How does open space conservation affect housing prices and local property taxes? Is the amount of open space available in 2011 in different UAs socially optimal? Theoretically, open space should be maintained at the level where the marginal social benefit of open space equals the marginal social cost. But in practice, this rule is difficult to implement because it is difficult to measure the social benefits and costs of open space conservation. For example, open space conservation may generate much larger amenity benefits in cities with high development densities and relatively little

open space than in smaller cities surrounded by rural land. The effect of open space conservation on land values also varies significantly across communities, depending on the price elasticity of land supply. Given the effect of induced land scarcity on prices, open space conservation will likely increase land values even if it does not generate any amenities. However, the effect is likely small in an urban area where land supply is highly elastic because any land removed from the path of bulldozers may be replaced by lands converted from other uses (Wu, 2014). Likewise, opportunity costs of open space conservation also vary significantly across local authorities with different fiscal conditions.

The purpose of this paper is two-fold. Its first objective is to develop a theoretical model to identify the key factors determining the optimal amount of open space in an urban area. The model reveals the conditions under which open space can increase: a) property tax rates, b) the level of public services, c) total land values, and d) social welfare. Its second objective is to empirically test the effects of the key factors identified in the theoretical model on the amount of open space in U.S. urban areas and investigate how open space affects property tax rates and local public services. The empirical analysis also evaluates whether the amount of open space in different UAs in 2011 is socially optimal.

To address the objectives of the study, a comprehensive database is compiled for 1656 UAs and 313 Core Based Statistical Areas (CBSAs) in the United States. The database includes information on land cover and use, open space area, housing prices, income, population density, local property tax rates, public expenditures, and other socioeconomic and demographic characteristics of the urban areas. Findings from the theoretical model suggest that the price elasticities of supply and demand for housing are the major factors that determine the effect of open space conservation on total property values. Thus, they significantly affect the amount of open space in an urban area. Open space conservation is likely to increase total land values and municipal services in urban areas with stringent land use regulations, high development densities, and relatively little open space, whereas it will probably reduce municipal services and total land values in relatively small, lightly regulated cities surrounded by rural land.

This paper builds on previous studies on open space conservation and local characteristics. Wu and Plantinga (2003) examine the effect of open space policy on urban development patterns and find that open space conservation can lead to more development as well as leapfrog development (i.e. development that skips over vacant land to build in a remote location). Walsh (2007) develops an equilibrium framework to analyse the impact of open space conservation and urban growth control policies on the entire metropolitan landscape. He finds that different strategies for open space conservation can have markedly different implications for the landscape and social welfare. Wu (2014) develops a theoretical model to analyse the fiscal and land value impacts of public open space conservation in a budget-constrained city, and finds that open space conservation is more likely to increase total land values and municipal services in metropolitan areas that have stringent land use regulations, high development densities, and relatively little open space. The present paper builds upon Wu (2014), but extends it to include environmental benefits from open space. In addition, it conducts an empirical analysis to identify the key factors that determine the amount of open space preserved in U.S. urban areas.

Many hedonic studies have evaluated the effect of open space on nearby property values (e.g. Acharya and Bennett, 2001; Anderson and West, 2006; Geoghegan, 2002; Geoghegan, Lynch and Bucholtz, 2003; Irwin, 2002; Irwin and Bockstael, 2001). These studies find that the value of proximity to open space is affected by many factors, including the nature and type of open space (e.g. public vs. private) and neighbourhood characteristics (e.g. income, crime, population density). The type of open space is also a critical determinant of its welfare impact (Klaiber and Phaneuf, 2010). This paper complements previous studies by examining the effect of open space conservation on *total* property values within an urban area, rather than focusing on its effect on *nearby* property values.

The rest of the paper is organised as follows. Section 2 develops a theoretical model to identify the key factors that influence a) the effect of open space conservation on property values and local public finance, and b) the optimal amount of open space. Section 3 describes the empirical approach and estimation methods. Section 4 presents the data used in the analysis. Section 5 discusses the empirical results. Section 6 concludes.

2. THE THEORETICAL MODEL

This section describes the theoretical model developed to identify the determinants of open space conservation in an urban area. The model considers an urban area that provides public open space and municipal services to local residents and finance those services through local property taxes. The local government chooses the property tax rate, the amount of open space, and the level of municipal services to maximise social welfare, subject to a budget constraint, where social welfare is defined as the sum of economic and environmental benefits from open space and municipal services.

The model builds on Wu (2014) and extends Poterba's framework of real property values (Poterba, 1991) to include open space amenities and municipal services. According to Poterba's framework, equilibrium in a real property market requires that the return on real property investments, such as a parcel of developable land, equals the user cost of ownership: $c_0 = r/P$, where P is the land price, r is the rental value of housing services provided by the land, and c_0 is the user cost of ownership, which includes the local property tax rate, the mortgage interest rate, and other costs associated with owning the property. Alternatively, the equilibrium condition can also be written as: $P = r/c_0$, which states that the value of land for residential development equals the present value of the stream of housing services provided by the land, discounted at the user cost of ownership. Expanding this condition to include the capitalisation of municipal services and open space amenities, the average value of land for residential development in the urban area, P , can be written as:

$$P = \frac{r(S)g^m}{t + c}, \quad (1)$$

where

S = total amount of open space in the urban area, including both public and private open space,

$r(S)$ = average rental value of housing services in the urban area,

g = level of municipal services such as city water and sewer

m = elasticity of land value with respect to municipal services

τ = property tax rate

c = other components of the user cost of ownership (e.g., mortgage interest rate, maintenance cost).

Previous hedonic studies find that the value of proximity to open space is affected by the nature and type of open space (e.g., public vs. private open space) and neighbourhood characteristics (e.g. income, crime, density). This paper abstracts from the location and pattern of open space and uses $r(S)$ to denote the average rental value of housing services within the urban area when S units of land is devoted to open space. Open space conservation can affect rental values by influencing both the demand and supply of housing. Open space provides amenities, which may attract more households into the urban area and thus increase the demand for developable land. However, when too much land is vacant, fragmentation may

become a disamenity and discourage development. Thus, the demand for housing services, $H^d(r, a(S))$, depends on the rental rate r and the level of open space amenities in the urban area $a(S)$, and $H^d(r, a(S))$ can increase or decrease with S . The supply of housing services equals $H^s(r, S) = h^s(r)[A(S) - S]$, where $h^s(r)$ is the level of housing services provided per unit of land and increases with rent, and $A(S)$ is the total urban area, including urban open space. Open space removes land from the path of bulldozers, but encourages development by providing amenities. Thus, the total developed area can increase or decrease with S (Wu and Plantinga, 2003). Formally, $r(S)$ is defined by $H^d(r, a(S)) = H^s(r, S)$. Differentiating this equation with respect to S gives:

$$\frac{dr}{dS} = \frac{r}{As(1-s)(\epsilon_r^{H^s} - \epsilon_r^{H^d})} [(s - \epsilon_S^A) + (1-s)\epsilon_S^{H^d}] \quad (2)$$

where

$$\epsilon_S^A = \frac{dA(S)}{dS} \frac{S}{A}, \quad e_r^{H^d} = \frac{\eta_{H^d}}{\eta_r} \frac{r}{H^d} < 0, \quad e_r^{H^s} = \frac{\eta_{H^s}}{\eta_r} \frac{r}{H^s} > 0, \quad \text{and} \quad e_S^{H^d} = \frac{\eta_{H^d}}{\eta_S} \frac{S}{H^d}. \quad (3)$$

Both $\epsilon_S^{H^d}$ and ϵ_S^A can be positive or negative depending on whether the amenity or fragmentation effects dominate. The share of open space in the urban area is $s = S/A(S)$.

Equation (2) indicates that the more inelastic the housing supply and demand are, the larger the effect of open space on residential land rent. However, the effect can be positive or negative. If $\epsilon_S^A < s$ and $\epsilon_S^{H^d} > 0$, open space conservation increases the housing rent because it reduces the total housing supply and increases the total housing demand. On the other hand, if $\epsilon_S^A > s$ and $\epsilon_S^{H^d} < 0$, open space conservation reduces the housing rent because it increases the total housing supply, and reduces the total housing demand.

Assume all land except open space is assessed for taxes. The total property tax revenue, T , for the city is

$$T = t[A(S) - S]P = \frac{t[A(S) - S]r(S, a(S))g^m}{t + c}. \quad (4)$$

The city's annualised cost of open space conservation is

$$C^s = cSP = \frac{cSr(S, a(S))g^m}{t + c}. \quad (5)$$

The cost of municipal services is assumed to be:

$$C^g = g(A - S)^\lambda, \quad (6)$$

where $\lambda \in [0, 1]$ is a parameter indicating the economies of scale in the provision of municipal services, with $\lambda = 1$ indicating no economies of scale and $\lambda = 0$ indicating that all municipal services are pure non-rival public goods.

The local government chooses the property tax rate, the level of municipal services, and the amount of open space to maximise social welfare subject to a budget constraint:

$$\underset{(t, g, S)}{\text{Max}} \quad SW = A(S)[P(t, g, S) - P_0] + B(S), \quad (7)$$

$$s.t. \quad C^s + C^g \leq T, \quad (8)$$

where P_0 is the land price without public services and open space. Thus, the first term in (7) represents the economic and environmental benefits of open space that are capitalised into the property values in the urban area, and the second term represents those that are not. For example, some of the environmental benefits from open space, such as wildlife habitat, may be valued by the public, but may not be capitalised into the land value. The aggregate amount of such benefits is denoted by $B(S)$.

Solving the first-order conditions of the maximisation problem, the property tax rate and the level of municipal services can be expressed as a function of the amount of open space in the urban area:

$$t^* = \frac{c}{1-m} \left(m + \frac{s}{1-s} \right), \quad (9)$$

$$g^* = \left[\frac{mr(S, a(S))}{[A(1-s)]^{1-m}} \right]^{\frac{1}{1-m}} \quad (10)$$

Substituting (9) and (10) into (7) and the total land value function $TLV = A(S)P(\tau, g, S)$ and then differentiating τ^* , g^* , TLV , and SW with respect S , the following conditions are obtained:

$$\frac{d\tau^*}{dS} > 0 \text{ iff } \varepsilon_S^A < 1, \quad (11a)$$

$$\frac{dg^*}{dS} > 0 \text{ iff } (\varepsilon_S^A - s) \left[(1-\lambda)(\varepsilon_r^{H^s} + \varepsilon_r^{H^d}) - 1 \right] + (1-s)\varepsilon_S^{H^d} > 0, \quad (11b)$$

$$\frac{dTLV}{dS} \geq 0 \text{ iff } (\varepsilon_S^A - s) \left[(1-\lambda\mu)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1 \right] + (1-s)\varepsilon_S^{H^d} \geq 0 \quad (11c)$$

$$\frac{dSW}{dS} \geq 0 \text{ iff } (\varepsilon_S^A - s) \left[(1-\lambda\mu)(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1 \right] + (1-s) \left[\varepsilon_S^{H^d} + \nu(\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) \right] \geq 0, \quad (11d)$$

where $\nu = \frac{S \cdot \frac{dB}{dS}}{TLV}$ is the value of non-capitalised environmental benefits from open space relative to the total land value.

Finally, from (11d), the optimal share of open space in the urban area can be derived:

$$s^o = \frac{\varepsilon_S^{H^d} + [(1-\lambda\mu)\varepsilon_S^A + \nu](\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - \varepsilon_S^A}{\varepsilon_S^{H^d} + [(1-\lambda\mu) + \nu](\varepsilon_r^{H^s} - \varepsilon_r^{H^d}) - 1}. \quad (12)$$

Setting $\nu = 0$ in (12), the share of open space that maximises the total land value within the urban area, s^* , is obtained.

The theoretical analysis provides several interesting findings. First, open space increases the property tax rate if, and only if, the open space share, s , increases with open space conservation (i.e. $\varepsilon_S^A < 1$). Intuitively, when $\varepsilon_S^A < 1$, open space conservation reduces the share of land where property taxes are levied and thus leads to increases in the property tax rate. On the other hand, when $\varepsilon_S^A > 1$, open space conservation increases the tax base as a percentage of the total urban area, which leads to a reduced property tax rate.

Second, equation (11b) states that open space conservation can increase or decrease the level of municipal services. When $\varepsilon_s^A < s$, open space conservation reduces the total developed area within the city, which will lead to an increase in the level of municipal services if the demand and supply of housing services are sufficiently price inelastic and if open space does not generate disamenities. By reducing the total developed area, open space conservation increases the rental value of housing services and hence the marginal benefit of municipal services, leading to more municipal services. The results for $\varepsilon_s^A > s$ can be similarly interpreted.

Third, equation (11c) states that open space conservation increases the total land value, even if it generates no amenities. If open space reduces the total developed area (i.e. $\varepsilon_s^A < s$) and the demand and supply of housing are sufficiently price inelastic, land scarcity created by open space conservation leads to increased total land value. Conversely, if the demand and supply of housing services are sufficiently price elastic, open space conservation reduces total land value within the urban area.

Fourth, the effect of open space conservation on total land value depends on local characteristics. In small cities surrounded by rural land, extra open space may not generate additional amenities or land scarcity because there are close substitutes for new open space and developable land and the demand and supply of housing are likely to be price elastic. Open space conservation in such cities will likely reduce total land value. In contrast, in large cities with high development densities, and inelastic demand and supply of housing, large parcels of new open space tend to provide important amenities and create additional land scarcity. In those cities, open space conservation tends to increase total land value.

Finally, by using the necessary and sufficient conditions and the parameter values estimated in the empirical analysis, it can be evaluated whether the amount of open space in an urban area is socially optimal, i.e. whether it is maximising total land value. The empirical approach used in the study is discussed in the next section.

In sum, the model provides interesting insights. Open space conservation removes land from development and creates land scarcity, which tends to raise land prices. Hence, open space conservation can increase total property values, even if it does not generate any amenities. However, open space conservation may also reduce the total developed area. When the demand and supply are sufficiently inelastic, the effect of open space conservation on land prices dominates, leading to an increase in total land value within the urban area. The effect of open space conservation on land value depends on the amount of land preserved – little open space conservation will likely increase the total land value, while too much open space conservation tends to have the opposite effect.

3. EMPIRICAL ANALYSIS

The purpose of the empirical analysis is two-fold. It first tests if the factors identified in the theoretical model indeed affect open space conservation and local public finance. It then evaluates if the amount of open space in U.S. urban areas in 2011 are socially optimal. A prerequisite to achieving these objectives is to estimate housing demand and supply elasticities for each Core Based Statistical Areas (CBSA), as they determine both the optimal amount of open space and its effect on municipal characteristics.

3.1. Estimating housing demand and supply elasticities

A number of previous studies have estimated housing demand or supply elasticities. For example, Green, Malpezzi and Mayo (2005) estimate the elasticity of new housing supply (measured by the number of new housing permits issued) for 45 U.S. Metropolitan Statistical Areas (MSAs). This paper expands Green, Malpezzi and Mayo (2005) to estimate elasticities of both housing demand and housing supply for the 313 Core Based Statistical Areas (CBSAs) in the sample. CBSAs are geographical entities delineated by the U.S. Office of Management and Budget (OMB) for use by Federal statistical agencies in collecting, tabulating, and publishing Federal statistics. CBSAs comprise two classes of statistical areas: Metropolitan Statistical Areas (MSAs) and Micropolitan Statistical Areas (μ SAs). An MSA contains a core urban area of 50 000 or more inhabitants, and a μ SA contains an urban core of at least 10 000 – but less than 50 000 – inhabitants.

Housing markets across CBSAs are diverse and, thus, a separate set of housing demand and supply equations are estimated for each CBSA. Estimations are based on time-series data and the following equations:

$$H_t^S = F(P_t, S_t, w_t) + \varepsilon_t^S, \quad (1a)$$

$$H_t^D = G(P_t, I_t, S_t, g_t, F_t) + \varepsilon_t^D, \quad (1b)$$

where

t = a year index;

H_t^S = Total housing supply in year t , measured by the number of existing housing units plus new housing permits issued;²

H_t^D = Total housing demand in year t , measured by total housing expenditure (including mortgage) divided by the Freddie Mac housing price index;

P_t = The Freddie Mac housing price index in year t ;

w_t = input prices for housing construction, including average wage rates for construction workers in year t ;

I_t = household income in year t ;

s_t = share of open space in the total area of the CBSA in year t ;

g_t = per-capita spending on municipal services in year t ;

F_t = urban fragmentation in year t ;

$\varepsilon_t^S, \varepsilon_t^D$ = the error terms.

² There are alternative ways to measure housing supply. Green, Malpezzi and Mayo (2005) use the number of new housing permits issued to measure the supply. But this does not capture the houses on sale. In addition, all houses could potentially be offered for sale. Thus, total housing supply is measured by the number of existing housing units plus new housing permits issued. This measure of housing supply aligns well with the way in which housing demand is measured.

A number of challenges and trade-offs emerge when selecting a specific empirical approach to estimate the housing demand and supply equations. First, the issue of endogeneity must be addressed. Housing price P_t is endogenous, which suggests it is more appropriate to estimate the demand and supply equation as a simultaneous equation system. Both equations in the system would be overly identified if I_t, S_t, g_t, F_t, w_t , could be treated as exogenous variables; the problem is that some of these variables are also endogenous. For example, the open space area may change in response to changes in housing prices. In addition, the dataset contains only three time points for open space share and urban fragmentation (2001, 2006, and 2011) and for per capita expenditure on municipal services (2002, 2007, and 2012). In contrast, longer time series are available for other variables (see the data section below). It would be possible to estimate the housing demand and supply equations using panel data, but a lot of information would be ignored by doing so. More importantly, it would be extremely difficult to capture all time-variant factors that vary across urban areas. Given this, it is better to estimate a separate set of demand and supply equations for each urban area using time-series data.

To address the potential endogeneity problems associated with S_t, g_t , and F_t , a fixed effects model is first estimated to predict their values:

$$S_{it} = \zeta_{0i} + \zeta_1 income_{i,t-10} + \zeta_2 pop_{i,t-10} + \zeta_3 mortgage_{it} + e_{it}, \quad (2)$$

where $i = 1, \dots, I$ indicates CBSAs; and $t = 2001, 2006, 2011$.

A similar model is specified for g_t and F_t . This specification is based on the theoretical model, which indicates that income, population, and mortgage interest rate are the key determinants of these variables. Both income and population are lagged 10 years to avoid endogeneity. The estimated models are used to predict the share of open space in the total area of the CBSA, urban fragmentation, and per-capita expenditure on municipal services from 1975 to 2014. This approach simultaneously addresses the endogeneity problem and the missing values problem associated with these three variables in the housing demand and supply equations.

A difficulty in estimating the housing demand and supply equation arises from the fact that there is no direct measure of housing demand. Housing demand in a CBSA is, therefore, approximated by dividing total housing expenditure (including mortgage) by the Freddie Mac housing price index.³ The housing demand variable generally has much shorter time series than the housing supply variable. Table 1 provides a summary of data availability for housing demand and supply across CBSAs.

Given the data issues identified above, two different empirical approaches are used to estimate the housing demand and supply equations. For each approach, two alternative econometric models are tested; log-linear and linear. The first approach is to follow Green, Malpezzi and Mayo (2005) and use the lagged housing price variable, P_{t-1} , and the predicted values of S_t, g_t , and F_t to avoid simultaneity problems. This approach allows the estimation of the housing demand and supply equations as a Seemingly Unrelated Regression (SUR) model. The second approach is to estimate (1a) and (1b) separately using Ordinary Least Squares (OLS) and lagged variables to avoid simultaneity problems (i.e. $P_{t-1}, I_{t-1}, \hat{S}_{t-1}, \hat{g}_{t-1}, \hat{F}_{t-1}$). This approach could lead to better estimates of the supply equation than the first two approaches because it uses a longer time series when estimating the supply equation.

³ The housing demand variable before 2005 is in MSA delineation; it is adjusted to the CBSA level using the Geographic Correspondence Engine (see <http://mcdc2.missouri.edu/websas/geocorr2k.html>).

Table 1. Summary of data availability for the housing demand and supply variables

Supply			Demand		
Year	% CBSA	# time periods	Year	% CBSA	# time periods
2003-2014	19%	12	2005-2014	11%	10
2000-2014	4%	15	2000, 2005-2014	62%	11
1995-2014	48%	20	2000, 2002-2014	8%	14
1980-2014	30%	35	2000-2014	19%	15

3.2. Testing the empirical significance of the key parameters

Once the housing demand and supply elasticities are estimated, they can be used to test whether the key variables identified in the theoretical model (see Section 2) are indeed significant empirically. To this end, the following simultaneous fixed-effects equation system is estimated:

$$\tau_{it}^* = \alpha_{0i} + \alpha_1 s_{it}^* + \alpha_2 c_{it} + \alpha_3 X_{it} + e_{it}^{\tau}, \quad (3a)$$

$$g_{it}^* = \beta_{0i} + \beta_2 s_{it}^* + \beta_2 c_{it} + \beta_3 Y_{it} + e_{it}^g, \quad (3b)$$

$$s_{it}^* = \gamma_{0i} + \gamma_1 \varepsilon_{Sit}^{H^d} + \gamma_2 \varepsilon_{rit}^{H^d} + \gamma_3 \varepsilon_{rit}^{H^S} + \gamma_4 \varepsilon_{Sit}^A + \gamma_5 Z_{it} + e_{it}^s, \quad (3c)$$

where i is an index of CBSAs, t denotes years, c_{it} is a vector of variables measuring user costs of homeownership, such as the mortgage interest rate and property insurance payments, and α 's, β 's, and γ 's are parameters to be estimated; e 's are error terms. The property tax rate equation (3a) is specified based on equation (12), which shows that in addition to the share of open space s and the user cost of land ownership c , parameter μ and the total surface of urban area A also affects the property tax rate. Parameter μ denotes the elasticity of land value with respect to the quality of municipal services and reflects household preferences and willingness to pay for public services. Vector X_{it} is included in (3a) to capture the effect of parameter μ and A on the property tax rate.

The public services equation (3b) is specified based on equation (11), which shows that in addition to the amount of open space S and the user cost of land ownership c , parameters λ – which measures the economies of scale in providing municipal services – and μ and A also affect the level of municipal services. The vector Y_{it} is included in (3b) to capture the effect of these parameters.

The open space share equation (3c) is specified based on equation (20), which shows that in addition to all the elasticity variables, parameters λ , μ , ν also affect the optimal share of open space. Parameter ν denotes the implied value of non-capitalised environmental benefits from open space relative to the total housing value in the CBSA. Vector Z_{it} aims to capture the effect of these parameters.

The equation system (3a)-(3c) is recursive in that the open space share s_{it}^* appears in the property tax rate equation (3a) and the level of municipal service equation (3b), but the property tax rate τ_{it}^* and the level of municipal services g_{it}^* do not appear in the open space share equation. Both equations (3a) and (3b) are overly identified, and the equation system is estimated using three-stage least squares (3SLS).

Substituting (3c) into (3a) and (3b) results in a set of reduced form equations. Reduced form equations are then estimated as a Seemingly Unrelated Regression (SUR) system. The advantage of the simultaneous approach is that it allows to directly test if the amount of open space in an urban area is correlated with its property tax rate and public services. The paper reports results from both approaches.

The empirical analysis also includes a series of robustness checks on the estimation results of models (3a)-(3c). First, the housing demand and supply elasticities included in (3c) and in each of the reduced form equations must be estimated. Using the estimated values of elasticities in the regression models does not only help alleviate the potential endogeneity concerns associated with these elasticities, but also provides opportunities for robustness checks.

Finally, the robustness of the estimation results is tested by including alternative control variables in equations (3a)-(3c). Two approaches could be used to select variables for X_{it} , Y_{it} and Z_{it} . One is to assume that μ , λ and ν do not change much over a short period of time, and their effects are captured by the fixed effects. Under this approach, no variables are included in for X_{it} , Y_{it} and Z_{it} (control specification 1). Alternatively, one could try to identify time-varying variables that affect μ , λ and ν and include those variables in X_{it} , Y_{it} and Z_{it} (control specification 2). Income, education, and age are commonly believed to affect preferences and willingness to pay for goods and services and thus could be included in X_{it} as control variables. Parameter λ may be affected by variables such as total population, total developed area, and patterns of urban development. Thus, in addition to including income, education, and age, one could include total population, total developed area, and the degree of fragmentation in Y_{it} . Regarding Z_{it} , in addition to including all variables in Y_{it} , one could include proxy variables for ν , including those that affect the environmental benefits from additional open space conservation, such as variables that reflect the existing land use and land use patterns in the urban area.

Although specification 2 allows examining how income, education, age, water area, and other demographic and topographic features are correlated with open space conservation and local public finance, it may suffer endogeneity problems. With open space conservation, some high-income households may be attracted to the urban area. Thus, variables such as income, education, and total population are likely to be simultaneously determined with the open space area. When these potentially endogenous variables are included in the model, it could lead to biased estimates. Although both specifications are run to test the robustness of the empirical results, the first control specification is preferred over the second.

3.3. Approach to examine if the amount of open space is optimal

The parameter values estimated in the empirical analysis can be combined with those found in the literature to test if more open space conservation can increase the total land value in an urban area (see equation (16)). An increase in total land value also implies an increase in social welfare, as long as additional open space does not generate disamenities. On the contrary, if reducing the amount of open space is found to increase the total land value in an urban area, local residents are sacrificing or relinquishing some land value for open space. This sacrifice could be justified if the amount of non-capitalised environmental benefits is large enough.

If one now assumes that the existing amount of open space in an urban area is socially optimal, the implied value of environmental benefits from open space relative to the total land value ν can be calculated by solving equation (20). For example, if the implied value of ν equals one, the value of non-capitalised environmental benefits from open space must be at least as large as the total land value within the urban area to justify the amount of open space in the urban area. If people's willingness to pay for the non-capitalised environmental benefits is smaller (larger) than the total land value, then the urban area has too much (little) open space.

4. DATA

The paper compiles a panel dataset that covers 1656 U.S. urban areas (see U.S. Census Bureau). Although detailed land-use data are used for each UA for three years (2001, 2006, 2011), most of the other data are available only at the Core Based Statistical Area (CBSA) level. Therefore, all data are aggregated to the CBSA level for the econometric analysis. Figure 1 shows the 1656 UAs (the green areas) and their corresponding CBSAs in 2010.⁴

Figure 1. U.S. CBSA and UA boundaries

4.1. Data on open space and other dependent variables

Land use and open space data for each UA are generated using the National Land Cover Database (NLCD), issued by the Multi-Resolution Land Characteristics (MRLC) Consortium (Jin et al., 2013). The NLCD allows the comprehensive assessment of land cover changes and trends across the United States from 2001 to 2011. The NLCD provides land cover data at a spatial resolution of 30 meters over 16 land cover classes, based on the Anderson Land Cover Classification System. Four land cover classes (Dwarf scrub, sedge/herbaceous, lichens, and moss) exist only in Alaska, which is excluded from this study because of the short growing season and scarcity of cloud free imagery. The remaining 12 land cover classes, along with their summary statistics, are listed in Table 2.

⁴ Even though most UAs lie within a single CBSA, some overlap between multiple CBSAs. In this analysis, a UA qualifies as overlapping if 25% or more of its surface lies outside its main CBSA (only fragments with at least 20% of the UA within a single CBSA are kept and considered overlaps). For example, considering Beloit (WI-IL), 65% of its surface is in Janesville, WI and 35% in Rockford, IL. Only 40 out of the 1656 UAs overlap.

One of the land cover classes that is particularly relevant to this study is “Developed: Open Space”. It comprises “*areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20% of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes*” (The Multi-Resolution Land Characteristics (MRLC) consortium, 2015).

Figure 2 shows the percentage of developed open space in total land area in U.S. UAs in 2011. UAs in the Southeast have much more developed open space than any other part of the country. In contrast, in the Northeast and most urban areas on the West Coast and the Great Lake, the percentage of developed open space is lower. Figure 3 shows the percentage changes in developed open space from 2001 to 2011 across UAs. Developed open space has increased in most urban areas during this period, except for some urban areas in the West Coast, Southern Plains, Florida Coast, and Michigan.

Table 2. Summary statistics of land cover for 1656 Urban Areas in the U.S., in square kilometres

Types of LC	Mean			Standard Deviation		
	2001	2006	2011	2001	2006	2011
Open Water	3.6	3.6	3.7	18.9	18.8	19.2
Developed. Open Space	30.5	30.4	31.3	111.0	110.3	113.9
Developed. Low Intensity	32.9	36.1	34.6	120.7	131.7	126.0
Developed. Medium Intensity	19.4	21.0	23.2	88.4	95.1	100.7
Developed. High Intensity	7.5	7.6	8.9	38.1	38.7	43.3
Barren Land (Rock/Sand/Clay)	0.8	0.7	0.7	4.8	3.4	3.3
Deciduous Forest	15.5	15.0	14.1	76.7	75.6	69.0
Evergreen Forest	5.2	4.6	4.4	33.2	29.4	27.3
Mixed Forest	1.9	1.7	1.7	9.0	8.2	8.0
Shrub/Scrub	4.6	4.1	4.0	24.5	21.1	19.3
Grassland/Herbaceous	4.6	4.0	3.8	24.6	20.7	18.6
Pasture/Hay	7.6	7.0	6.2	26.3	24.0	20.6
Cultivated Crops	7.4	6.2	5.6	26.7	21.3	18.6
Woody Wetlands	5.8	5.5	5.3	30.2	27.6	27.8
Emergent Herbaceous Wetlands	1.4	1.3	1.3	8.0	7.3	7.5

Figure 2. Developed Open Space in U.S. Urban Areas in 2011

Source: The data and map are generated using the National Land Cover Database (NLCD) created by the Multi-Resolution Land Characteristics (MRLC) Consortium.

The other two dependent variables in the simultaneous equation system (3a)-(3c) are the property tax rate and the level of municipal services. The property tax rates in each CBSA were calculated using data from the U.S. Census Public Use Microsamples (PUMA) dataset. Two PUMA's responses were used in the calculation of the property tax rates: the self-reported value of the property, and the self-reported amount of property tax paid. There are no data that directly measure the level of municipal services. The amount of per-capita expenditure on municipal services is, therefore, used to measure the level of municipal services. Expenditure on municipal services comprise expenditure on education, libraries, parking facilities, parks and recreation, housing and community development, sewerage, solid waste management, general public buildings, fire protection, and police protection. The county-level data on municipal services for 2002, 2007 and 2012 were obtained from U.S. Census of Bureau and aggregated to the CBSA level.

Housing price data are from the Freddie Mac Housing Price Index (FMHPI).⁵ The FMHPI is based on repeat transactions on one-family detached and town home properties serving as collateral on loans obtained between 1975 and 2015.

⁵ See www.freddiemac.com/finance/house_price_index.html.

Figure 3. Changes in the percentage of land devoted to developed open space in U.S. UAs: 2001-2011

Source: the data and map are generated using the National Land Cover Database (NLCD) created by the Multi-Resolution Land Characteristics (MRLC) Consortium.

4.2. Data on other parameter values

Other parameter values needed for evaluating the optimal amount of open space are the economies of scale in providing municipal services, λ , and the elasticity of land value with respect to the level of municipal services, μ . Regarding λ , Carruthers and Úlfarsson (2008) analyse local government expenditure in 3075 counties in the continental United States and report an estimate of 0.02 for the elasticity of per-capita direct government expenditure with respect to the percent of land area developed. Hortas-Rico and Solé-Ollé (2010) analyse the effect of urban expansion on local government spending in 2500 municipalities in Spain and find that the elasticity of per-capita spending with respect to urbanised area is 0.05-0.06. Both studies control for population density. Therefore, their results suggest that the value of parameter λ is close to 1 (see also Reiter and Weichenrieder, 1997). Thus, λ is set equal to 1.

There is an enduring debate about the capitalisation of local fiscal attributes into property values (Yinger, 1982). The debate has stimulated the performance of many empirical studies, dating back to the seminal article by Oates (1969). But relatively few studies directly estimate parameter μ . One exception is Potepan (1996), who uses the 1974-1983 Annual Housing Survey data to analyse variation in housing prices, rents, and land prices among 58 U.S. MSAs. Potepan (1996) finds that the quality of public services (measured by the percent of households reporting excellent or good quality of public services) is significant in explaining the variation in land prices, and reports an estimate of 0.68 for the elasticity of land price with respect to the quality of public services. Based on the empirical evidence, μ is set to 0.68.

5. EMPIRICAL RESULTS

This section presents the results of the empirical analysis. The econometric estimates of housing demand and supply elasticities are discussed first, followed by the estimates of the effects of key variables on open space conservation and local public finance. Finally, the section evaluates the extent to which the amount of open space in U.S. urban areas deviates from the optimal amount.

5.1. Estimated Demand and Supply Elasticities

Table 3 summarises the estimated demand and supply elasticities from four models estimated using either different functional forms (linear or log-linear) or estimation methods (SUR or OLS). The results suggest that total housing supply is highly inelastic, with the mean of the estimated price elasticities of housing supply ranging from 0.083 to 0.122 among the four types of models shown in Table 3. At least 65% of the estimated supply elasticities are statistically significant at the 10% level. Green, Malpezzi and Mayo (2005) provide estimates for only 45 MSAs using data from 1980 to 1997. Only 51% of the estimates in their study are statistically different from zero. The improvement of statistical significance is likely due to the increased number of observations (18 years in Green, Malpezzi and Mayo versus up to 34 years in this study). Green, Malpezzi and Mayo (2005) report a much higher estimate for the elasticity of housing supply. Although not explicitly stated, they estimate the price elasticity of new housing supply – as measured by new housing permits issued – instead of total housing supply. Using Green, Malpezzi and Mayo's empirical model, the relationship between the price elasticity of total housing supply ($\epsilon_r^{H^S}$) and the price elasticity of new housing supply (ϵ_r^{new}) can be derived as: $\epsilon_r^{H^S} = \epsilon_r^{new} \frac{\text{new permits}}{\text{total supply}}$. Given that the number of new permits is only a very small percentage of total housing supply, the elasticity of total housing supply ($\epsilon_r^{H^S}$) is much smaller than the price elasticity of new housing supply. Figure 4 shows price elasticities of housing supply in the CBSAs where the estimated elasticity has the expected sign. Generally, housing supply is more price elastic in the Midwest than in the east and west coast of the U.S..

Table 3. Summary statistics of estimated housing demand and supply elasticities
(a separate set of housing demand and supply equations and elasticities is estimated for each CBSA)

Elasticity Type	No. of CBSAs	MEAN ^a	STD ^a	Percent of CBSAs with significant elasticity ^b	Percent of CBSAs with elasticity of the expected sign ^c	Percent of significant elasticities having the expected sign
1. OLS log-linear model (average R-squared (supply)=0.75, average R-squared (demand)=0.77)						
Supply w.r.t. housing price	347	0.122	0.268	76.14%	93.14%	91.42%
Demand w.r.t. housing price	353	-0.419	0.754	40.20%	93.46%	95.92%
Demand w.r.t. open space	353	-1.307	5.905	12.75%		
2. OLS linear model (average R-squared (supply)=0.73, average R-squared (demand)=0.74)						
Supply w.r.t. housing price	347	0.122	0.174	77.45%	95.75%	93.67%
Demand w.r.t. housing price	353	-0.352	0.695	36.27%	90.52%	95.51%
Demand w.r.t. open space	353	-1.536	5.719	10.46%		
3. SUR log-linear model (average R-squared (supply)=0.73, average R-squared (demand)=0.74)						
Supply w.r.t. housing price	303	0.085	0.107	64.71%	82.35%	90.90%
Demand w.r.t. housing price	303	-0.369	0.689	39.54%	79.41%	94.21%
Demand w.r.t. open space	303	-0.928	4.128	16.34%		
4. SUR linear model (average R-squared (supply)=0.71, average R-squared (demand)=0.71)						
Supply w.r.t. housing price	306	0.083	0.111	67.32%	83.99%	91.27%
Demand w.r.t. housing price	306	-0.307	0.663	34.97%	78.10%	92.51%
Demand w.r.t. open space	306	-1.278	4.054	17.32%		

^a Mean and standard deviation for elasticity estimates for individual CBSAs.

^b Significant at least at the 10% level.

^c $\varepsilon_r^{H^d} < 0, \varepsilon_r^{H^s} > 0$.

The mean of the estimated price elasticities of housing demand ranges from -0.307 to -0.419 in the four models shown in Table 3. The percent of CBSAs whose estimated elasticities have the expected sign varies from 78% to 96% across models. At least 90% of significant elasticities have the expected sign for all models. However, only 35%-40% of the estimated price elasticities of housing demand are statistically significant at the 10% level. Figure 5 shows price elasticities of housing demand in the CBSAs where the elasticity has the expected sign. The estimated elasticities reveal that housing demand is price inelastic, which is consistent with previous findings (see e.g. Hanushek and Quigley, 1980; Polinsky and Ellwood, 1977).

Figure 4. Price Elasticity of Housing Supply in U.S. CBSAs

Figure 5. Price Elasticity of Housing Demand in U.S. CBSAs

Few previous studies report estimates of housing demand elasticity with respect to open space. The results presented here indicate that open space is not a major determinant of housing demand. Only 10-17% of the estimated housing demand elasticities with respect to open space area are statistically significant at the 10% level. The mean elasticity of housing demand with respect to open space is negative, indicating that increasing the share of open space may actually lead to a lower demand for housing in many CBSAs. Those CBSAs may already have too much open space and additional open space will lead to lower demand for housing.

5.2. Open space, property tax rates, and public services

Equations (3a)-(3c) are estimated both as a simultaneous equation system and as separate fixed-effects models. The results are reported in Tables 4 and 5, respectively. For both the simultaneous and separate reduced-form equations, two sets of results are reported. The first set is estimated using the elasticities from the SUR linear models (Model A), and the other using the elasticities from the OLS linear models (Model B).⁶ The results are generally robust across the models in terms of signs and magnitude of estimated coefficients. Open space share has a positive coefficient in both the property tax rate equation and the government expenditure equation. It is also statistically significant in both equations in model B and in the government expenditure equation in model A. This provides evidence that CBSAs with a larger share of land devoted to open space tend to have a higher property tax rate and a larger per-capita spending on municipal services. Higher mortgage interest rates are associated with lower property tax rates and lower per capita government spending on municipal services. This result may reflect that when households face higher mortgage and insurance payments, they are less willing to be taxed to improve municipal services.

Both the elasticity of housing demand with respect to open space and the elasticity of total developed area with respect to open space are positive and statistically significant at the 1% level in the open space share equation. This suggests that CBSAs where housing demand and total developed area are more responsive to changes in the share of open space tend to have a larger share of land in open space. The coefficient of the price elasticity of housing supply is positive, while the coefficient on the price elasticity of housing demand is negative. Although the results are consistent with the theoretical model, only the coefficient of the price elasticity of housing supply is statistically significant in model B.

⁶ The simultaneous and reduced-form equations have also been estimated using the other specifications discussed in section 4.2.

Table 4. Estimation results of simultaneous equations of property tax rate, public expenditure, and open space share (3SLS, fixed-effects models)

VARIABLES	Model A (elasticities from SUR linear models of housing demand and supply)			Model B (elasticities from OLS linear models of housing demand and supply)		
	Property tax rate	Government expenditure	Open space share	Property tax rate	Government expenditure	Open space share
Open space share	1.49e-04 (1.10e-04)	4,397** (1,717)		2.35e-04** (1.05e-04)	3,819** (1,623)	
Mortgage interest rate	-2.12e-05*** (9.83e-07)	-38.66** (15.41)		-2.13e-05*** (9.30e-07)	-35.19** (14.45)	
Property insurance payment	-1.58e-07*** (9.82e-09)	1.026*** (0.154)		-1.53e-07*** (9.47e-09)	1.013*** (0.147)	
Price elasticity of housing supply			-0.0146 (0.0327)			-0.0443** (0.0202)
Price elasticity of housing demand			1.80e-03 (1.98e-03)			2.87e-03 (1.85e-03)
Elasticity of housing demand w.r.t. open space share			9.92e-04*** (3.75e-04)			9.06e-04** (3.69e-04)
Elasticity of total developed area w.r.t. open space share			1.543*** (0.0767)			1.525*** (0.0746)
Constant	4.70e-04*** (4.46e-05)	-523.3 (698.9)	0.134*** (0.0139)	4.37e-04*** (4.30e-05)	-327.3 (665.1)	0.140*** (0.0134)
Observations	558	558	558	599	599	599
R-squared	0.941	0.933	0.992	0.941	0.938	0.988

Standard deviation in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

The results from the estimation of separate reduced-form equations are in agreement with those from the simultaneous equation models. They reaffirm that a higher user cost of homeownership, as reflected in higher mortgage interest rates and property insurance payments, reduces the property tax rate. Both the elasticity of housing demand with respect to open space and the elasticity of total developed area with respect to open space are positive and statistically significant at the 1% level in the property tax rate equation of both models.

Table 5. Estimation results of reduced-form equations of property tax rate, public expenditure, and open space share (SUR, fixed effects model)

VARIABLES	Model A (use elasticities from SUR linear model)			Model B (use elasticities from OLS linear model)		
	Property tax rate	Government expenditure	Open space share	Property tax rate	Government expenditure	Open space share
Mortgage interest rate	-1.15e-05*** (9.64e-07)	-70.29*** (18.96)		-1.18e-05*** (8.98e-07)	-68.94*** (17.75)	
Property insurance payment	-7.61e-08*** (8.65e-09)	0.684*** (0.170)		-7.84e-08*** (7.97e-09)	0.737*** (0.158)	
Price elasticity of housing supply	-1.82e-04*** (5.37e-05)	2,029* (1,055)	-0.0148 (0.0329)	-1.75e-04*** (3.21e-05)	541.6 (633.8)	-0.0361* (0.0205)
Price elasticity of housing demand	5.78e-05*** (3.62e-06)	-166.2** (71.12)	1.92e-04 (1.99e-03)	5.29e-05*** (3.26e-06)	-186.2*** (64.45)	5.46e-04 (1.86e-03)
Elasticity of housing demand w.r.t. open space share	3.62e-06*** (5.84e-07)	-3.961 (11.48)	8.69e-04** (3.78e-04)	3.48e-06*** (5.63e-07)	-3.341 (11.14)	7.22e-04* (3.74e-04)
Elasticity of total developed area w.r.t. open space share	3.90e-04*** (1.27e-04)	5,921** (2,490)	1.522*** (0.0767)	3.78e-04*** (1.20e-04)	5,747** (2,365)	1.514*** (0.0747)
Constant	3.68e-04*** (2.37e-05)	418.8 (466.9)	0.136*** (0.0139)	3.73e-04*** (2.26e-05)	539.9 (446.0)	0.140*** (0.0135)
Observations	558	558	558	599	599	599
R-squared	0.963	0.935	0.992	0.965	0.939	0.992

Standard deviation in parentheses. *** p<0.01, ** p<0.05, * p<0.1.

In summary, empirical results support the theoretical findings that the elasticities of housing supply and demand are key variables affecting the open space share, the property tax rate, and the level of municipal services. CBSAs with stringent land use regulations and high development densities tend to have lower elasticities of housing supply (Green, Malpezzi and Mayo, 2005; Oakley, 2014). Other things being equal, these CBSAs tend to have a lower property tax rate, and possibly a smaller share of land in open space, and a higher per-capita spending on municipal services.

5.3. Are the amounts of open space available in different CBSAs in 2011 socially optimal?

Using the housing demand and supply elasticities estimated in this study and the parameter values found in the literature for λ and μ (i.e., $\lambda = 1$ and $\mu = 0.68$), the property-value-maximising share of open space s^* can be calculated. If the share of open space does not equal s^* , using equation (11c), it can be determined if an increase in the amount of conserved open space leads to an increase in total land value. Finally, by assuming that a CBSA has the optimal amount of open space (i.e., $s^o = s$), the implied value of non-capitalised environmental benefits from open space relative to the total housing value within the CBSA, v , can be calculated. Specifically, from (12), v can be derived as:

$$\nu = \frac{(\varepsilon_S^A - s)[(1 - \lambda\mu)(\varepsilon_r^{H^S} - \varepsilon_r^{H^d}) - 1] + (1 - s)\varepsilon_S^{H^d}}{(1 - s)(\varepsilon_r^{H^S} - \varepsilon_r^{H^d})}. \quad (15)$$

If $\nu \geq 1$ in a CBSA, the non-capitalised environmental benefits from open space must be at least as large as the total land value to justify the amount of open space it has from a welfare perspective. Because it is hard to imagine that households are willing to pay more for non-capitalised environmental benefits from open space than for all the land within the city, including their lots, CBSAs with $\nu \geq 1$ probably have too much open space.

Table 6 provides a summary of the estimates of the implied value of non-capitalised environmental benefits relative to total land values (ν), and the sign of the marginal effect of open space conservation on total land value from the four models shown in Table 3. It also reports results for two sets of subsamples: a) CBSAs where both the estimates of price elasticities of housing demand and supply ($\hat{\varepsilon}_r^{H^S}, \hat{\varepsilon}_r^{H^d}$) have the expected sign; and b) CBSAs where the estimates of price elasticities of housing demand and supply have the expected sign and these estimates are statistically significant.

Table 6. Summary statistics for the estimates of the implied values of non-capitalised environmental benefits relative to the total land value and the marginal effect of open space share on total land value

Variables	Subsample A: CBSAs with housing price elasticity estimates of expected sign ^a			Subsample B: CBSAs with reliable and significant price elasticity estimates ^b		
	N	Mean	Std. Dev.	N	Mean	Std. Dev.
1. OLS log-linear model						
ν	224	0.35	5.12	66	0.73	3.38
% CBSAs with $\nu \geq 1$		33.5%			40.9%	
% CBSAs with $\frac{dTLV}{ds} > 0$		50.0%			42.4%	
2. OLS linear model						
ν	221	1.41	5.45	58	0.83	3.56
% CBSAs with $\nu \geq 1$		41.2%			36.2%	
% CBSAs with $\frac{dTLV}{ds} > 0$		44.3%			48.3%	
3. SUR log-linear model						
ν	200	0.32	5.33	76	1.36	3.84
% CBSAs with $\nu \geq 1$		35.0%			42.1%	
% CBSAs with $\frac{dTLV}{ds} > 0$		50.0%			43.4%	
4. SUR linear model						
ν	192	1.10	5.47	66	1.10	4.73
% CBSAs with $\nu \geq 1$		41.1%			37.9%	
% CBSAs with $\frac{dTLV}{ds} > 0$		43.2%			48.5%	

^a Estimates of price elasticity of housing demand and supply have the expected sign.

^b Estimates of price elasticity of housing demand and supply are statistically significant and have the expected sign.

There are 224 CBSAs in the first subsample. The estimated marginal effect of open space conservation on total land value is positive for 42-50% of the CBSAs, which suggests that open space conservation can increase the total land values and social welfare in those CBSAs as long as it does not generate disamenities. On the other hand, the estimated ν is no smaller than one for 34-41% of the CBSAs in these subsamples, which suggests that the total value of non-capitalised environmental benefits from open space must be at least as large as the total land value to justify the amount of open space they have. Figure 6 shows the sign of the estimated marginal effect of open space conservation on total land value for CBSAs in this subsample. The second subsample contains 76 CBSAs. The summary statistics of the estimates for this subsample are similar to the ones for the first subsample.

Figure 6. CBSAs where Increasing Open Space changes Total Land Values

Regardless of the models and subsamples used, results suggest that a significant share of U.S. urban areas has too little open space in the sense that additional open space conservation will increase total land values and social welfare as long as it does not generate disamenities. On the other hand, for at least 34% of CBSAs, the total value of non-capitalised environmental benefits from open space must be at least as large as the total land value within the urban area to justify the amount of open space they have.

6. CONCLUSIONS

Growing recognition of economic and environmental benefits from open space has sparked waves of conservation initiatives at local and state levels in the United States. As local governments invest more in open space conservation, it is important to understand its economic, fiscal and welfare implications. This paper investigates the key factors determining the effects of open space conservation on property values, local public finance, and social welfare and estimates the property-value-maximising and optimal amounts of open space in U.S. urban areas.

Several key insights have been gained from this study. First, even if open space conservation generates no amenities, it can still increase total land value within an urban area if the housing demand and supply are sufficiently price inelastic. In this case, the positive effect of open space conservation on land value (due to reduced land supply) outweighs the negative effect of increased property taxes, leading to a better quality of municipal services and higher property values. On the other hand, open space conservation will reduce total land value if it does not generate enough amenities and if the housing demand and supply are sufficiently price elastic.

Second, empirical results corroborate the theoretical findings that price elasticities of housing demand and supply are key parameters affecting the share of open space, the property tax rate, and the level of municipal services in an urban area. Specifically, a CBSA tends to have a larger share of land in open space and a higher property tax rate when its housing demand and total developed area are more responsive to open space and its housing supply is less price elastic. Higher user costs of homeownership as reflected in higher mortgage interest rates and higher property insurance payments tend to be negatively linked to property tax rates.

Finally, empirical results suggest that a significant share of U.S. urban areas has too little open space in the sense that additional open space conservation will increase total land values and social welfare as long as it does not generate disamenities. The most conservative estimate of the share of such urban areas in the sample used here is 42%, but less conservative estimates could be as high as 50%, depending on the model and subsample used. On the other hand, for about 38% of the U.S. urban areas of the sample, the total value of non-capitalised environmental benefits from open space must be at least as large as the total land value within the urban area to justify the amount of open space they have.

This study demonstrates that open space conservation is at the heart of a complex arbitration of forces influencing urban quality of life. Many factors determine the outcomes of this arbitration, including local housing market conditions, local geographic characteristics, local regulatory environments, and preferences and demographics of local residents. Although it may be challenging to determine the optimal amount of open space in an urban area, potential payoffs are likely high for each local jurisdiction to examine the existing amount, pattern, and types of open space and determine an appropriate short-term action plan and a long-term conservation strategy.

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APPENDIX

Table A. Fixed effects models of government expenditure, fragmentation, open space share, and total developed area)

VARIABLES	Government expenditure	The level of fragmentation	Open space share	Total land area
Personal income (10-year lag)	0.0746*** -6.14E-03	-1.79e-05*** -4.85E-06	-1.98e-06*** -3.10E-07	3.08e-04*** (7.19e-05)
Population (10-year lag)	-7.94e-04*** -1.69E-04	-5.80E-08 -1.06E-07	-7.03E-09 -6.78E-09	1.29e-04*** (3.50e-06)
Mortgage interest rate	65.78*** -17.64	0.109*** -0.0193	-2.03e-03* -1.23E-03	
Open space share				17.80 (19.78)
Constant	238.2 -229.1	1.796*** -0.216	0.400*** -0.0138	68.65*** (7.730)
Observations	1,115	1,056	1,056	1,065
Number of CBSAs	373	353	353	355
R-squared	0.296	0.474	0.23	0.734

Standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.