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# Endogenous open space amenities in a locational equilibrium

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**Abstract**

Little is known about the equilibrium impact of open space protection and growth control policies on the entire metropolitan landscape. This paper is an initial attempt to evaluate open space policies using an empirical approach that incorporates the endogeneity of both privately held open space and land conversion decisions in a locational equilibrium framework. The analysis yields four striking results. First, when one allows for endogenous adjustments in privately held open space, increasing the quantity of land in public preserves may actually lead to a decrease in the total quantity of open space in a metropolitan area. Second, different strategies for spending the same amount of money to purchase open space have markedly different landscape and welfare implications. Third, partial equilibrium welfare calculations are extremely poor predictors of their general equilibrium counterparts. And finally, the analysis suggests that while a growth ring strategy is most effective in reducing total developed acreage in the metropolitan area, this reduction in developed acreage is associated with a large net welfare loss.


## 1. Introduction

Across the United States local and state governments continue to adopt programs for protecting open space at a rapid pace. For example, according to the Trust for Public Lands, in 2005 there were 139 open space related ballot measures in the US. Of these, 111, or 80%, passed generating $2.7 billion in total funds, $1.7 billion of which is specifically dedicated for land conservation purposes. The proponents of these measures are motivated by concerns that include recreational access, habitat protection, ecological services, landscape amenities, and the prevention or reversal of perceived problems associated with urban sprawl. Opponents are concerned

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about the efficiency of such policies and argue that, at least in some cases, they can be viewed as rent-seeking by land owners who look to use public dollars and/or restrictive zoning to reduce the supply of developable land and thus drive up property values.

In spite of this ongoing policy debate, there is a lack of empirical evidence as to the long-run general equilibrium impacts of open space policies. Theorists have been active on the subject, but empirical work has been mainly restricted to partial equilibrium analysis that informs us about the value that household's place on open space amenities—remaining largely silent on the long-run land market equilibrium and welfare effects of these programs. Given that the distribution of landscape amenities that drive open space policy are inherently a function of the policies themselves, it is important to go beyond an understanding of what individual's value in the landscape and to develop better empirical models of exactly what are the long run landscape patterns and welfare consequences associated with open space protection policies. This paper endeavors to fill this void. Working with data from Wake County, North Carolina, one of the fastest growing metropolitan areas in the United States,[1] a locational equilibrium model of household preferences for landscape amenities is estimated. The results from this estimation are combined with an empirical model of land conversion decisions to develop a general equilibrium model of the land market in Wake County that incorporates the endogenous formation of landscape amenities.

Implementation of the analysis focusses on addressing four key issues associated with modeling open space policies. First, open space amenities are inherently spatial. An acre of land protected at location $A$ is not equal to an acre of land protected at location $B$. Second, non-marginal land protection policies will directly impact the land market equilibrium—leading households to make different location and lot size choices. Third, to evaluate how land protection policies affect the market equilibrium it is necessary to take account of heterogeneity in propensity for development across individual parcels. Finally, household adjustments in location and lot size in response to land protection policies create new patterns of development implying that some open space amenities will be endogenous.

The key findings of the analysis are as follows. First, when one allows for endogenous adjustments in privately held open space, increasing the quantity of land in public preserves may actually lead to a decrease in the total quantity of open space in a metropolitan area. Second, spatially different strategies for spending the same amount of money to purchase open space have markedly different landscape and welfare implications. Third, partial equilibrium welfare calculations are extremely poor predictors of their general equilibrium counterparts. And finally, the analysis suggests that while a growth ring strategy is most effective in reducing total developed acreage in the metropolitan area, this reduction in developed acreage is associated with a large net welfare loss.

## 2. Related literature

While the author is aware of almost no empirical work on the general equilibrium analysis of amenity driven land protection or zoning policies (see discussion of Cheshire and Sheppard [1] for the exception that proves the rule), there does exist a large empirical literature on the capitalization of open space amenities into housing values. For instance, in their overview of the open space valuation literature, McConnell and Walls [2] survey approximately 40 hedonic open space studies. A major challenge in these efforts is the need to develop quantitative descriptions of open

[1] Wake County's population expanded from 303,240 in 1980 to 513,901 in 1995. Construction of new single family homes has expanded from 3500 per year to 8000 per year over the last 10 years.

space amenities. In their early work on open space amenities in Boulder Colorado, Correll et al. [3] suggest that open space is both a public good which benefits everyone in the Boulder area and a 'quasi-public good' due to distance based exclusion of some protected parcels. The open space measures used in more recent empirical work follow a similar dichotomy and can typically be classified as either ambient or area measures capturing the general landscape character[2] or distance-based measures that capture direct access to open space amenities such as parks.[3] Both types of amenity measures have been consistently found to be associated with higher property values.

Several studies work within the mono-centric city framework to provide analysis of the impact of policies associated with "urban sprawl."[4] More recently, Bento et al. [14] evaluate the efficiency and distributional impacts of different anti-sprawl policies using a numerical general equilibrium framework. While these efforts provide valuable insights into the link between welfare, policy and city size, they assume that all open space is located at the urban boundary.

A unique departure to this work within the urban framework is the analysis of Cheshire and Sheppard [1]. Cheshire and Sheppard use hedonic methods to estimate implicit prices for "amenities produced by the planning system"[5] and then imbed these estimates in a modified monocentric city model[6] that is calibrated to data for the city of Reading in the United Kingdom. The fitted model is then used to calculate the gross monetized value of planning by calculating the change in household expenditure functions associated with the no planning outcome—assuming that without planning laws there would be no open space and that all industrial activity would be equally distributed across the landscape. Working within the framework of the traditional urban model allows Cheshire and Sheppard to implicitly incorporate general equilibrium adjustments in their analysis. Their results suggest that there is a net loss from planning activities that may be as high as 3.9% of annual incomes—with the largest positive benefits from these activities being associated with the provision of accessible open space.

The analysis presented here is similar to that of Cheshire and Sheppard in that it takes an empirical general equilibrium approach. However, the underlying model is much different. The approach taken here extends the empirical locational equilibrium model initially developed by Epple and Sieg [15]. Methodologically, the paper extends this approach in two dimensions. First, the analysis considers a Nash equilibrium with endogenous public goods where these goods arise 'naturally' as a result of land market outcomes. This is in contrast to the work of Epple et al. [16] who consider endogenous public goods that are consistent with majority voting. Second, unlike previous work with empirical locational equilibrium models, the analysis incorporates an empirically estimated supply model into the locational equilibrium framework.[7]

[2] For examples see: Garrod and Willis [4], Irwin and Bockstael [5], Acharya and Bennett [6], Bates and Santerre [7] and Geoghegan et al. [8].

[3] For examples see: Bolitzere and Netusil [9], Schultz and King [10], Smith et al. [11], and Anderson and West [12].

[4] See for instance Brueckner [13].

[5] These amenities include accessible and non-accessible open space and limitations on the distribution of industrial land uses.

[6] These authors allow the bid–rent function to vary in a radially symmetric fashion along different directions from the city center, incorporate preferences for both accessible and non-accessible open space that arises out of the planning process, and incorporate heterogeneity in preferences across demographic groups.

[7] Note that Sieg et al. [17] adapt the Epple and Sieg model to a G.E. framework that assumes constant elasticity housing supply functions. In this work however, the elasticity parameter is determined ad-hoc and is assumed constant across all locations.

## 3. Modeling open space

The analysis begins by marrying a model of household preferences for residential lots and open space with a spatially delineated static representation of lot conversion decisions to yield an equilibrium model of land markets incorporating the endogenous determination of privately held open space. Household preferences over spatially delineated neighborhoods incorporate heterogeneity in income and tastes and incorporates two distinct types of open space amenities. The decision to develop individual lots is modeled as a function of prices and lot characteristics. These parcel specific estimates are then aggregated to yield neighborhood level residential land supply functions.

### *3.1. Household preferences*

Preferences are defined over two distinct measures of open space, $O^p$, a measure of the distance from a given lot location to the nearest protected parcel of open space, and $O^n$, a measure of the percentage of a given lot's neighborhood which is in open space (both protected and unprotected). For each lot location, $O^p$ is assumed to be determined as the result of exogenous land protection policies.[8] $O^n$, on the other hand, is endogenous to the model and arises from the aggregation of development decisions and the exogenously determined land protection policies—it is essentially a residual equal to the neighborhood's area less the sum of its residential and commercially developed acreage.[9]

Household $i \in I$ maximizes its utility by choosing neighborhood $j \in J$. Each neighborhood is characterized by its land price $P_j$, open space amenities $O_j^p$ and $O_j^n$, and controls for additional spatially delineated amenities $A_j$. Households are characterized by their income $y_i$ and taste for neighborhood amenities $\alpha_i$. Implementation of the model is facilitated by adopting the indirect preference specification given in Eq. (1).

$$V\big(P_j, O_j^p, O_j^n, A_j \mid y_i, \alpha_i\big) = \left[\frac{1}{1-\nu} y_i^{1-\nu} - \frac{1}{1+\eta} B \widetilde{P}_j^{\eta+1}\right] G\big(O_j^n, A_j\big)^{\alpha_i}$$

$$\text{where:} \quad \widetilde{P}_j\big(P_j, O_j^p\big) = \frac{P_j}{1 + (O_j^p)^\lambda}. \tag{1}$$

The implications of this specification may not be immediately clear. First consider the role of $O^p$. This specification implements the pure re-packaging model suggested by Willig [18] and treats the private services provided by differential access to protected open space as a quality adjustment to an individual household's lot size. Under this specification, an individual will be indifferent between a doubling of her lot size or a doubling of the transformed measure of open space access: $1 + (O_j^p)^\lambda$. Because the price elasticity of land is less than one and the estimated value of the augmentation parameter, $\lambda$, is positive, this pure re-packaging approach leads $O^p$ to have a substitutes relationship with residential lot size. This inverse relationship is readily apparent from inspection of Eq. (2) below.

8 As discussed below, in order to implement the model, this measure is aggregated to the neighborhood level.

9 For tractability, the levels of non-residential development are treated as exogenous and are not formally modeled.

The overall functional from is one suggested by Hanemann [19][10] that results in the constant price ($\eta$) and income ($\nu$) elasticity demand specification given by Eq. (2).

$$L_{i,j}^D = B\frac{\widetilde{P}_j^{\eta} y_i^{\nu}}{1+(O_j^p)^{\lambda}} = B\frac{P^{\eta} y_i^{\nu}}{[1+(O_j^p)^{\lambda}]^{1+\eta}}. \tag{2}$$

This functional form is a generalization of Cobb–Douglass preferences which impose constant price and income elasticities of magnitude one.[11]

Finally, the neighborhood open space measure $O_j^n$ and controls for additional neighborhood specific amenities $A_j$ enter through a separable index of neighborhood public services, $G_j$ which is assumed to take the form: $\ln G_j = X_j'\gamma + \varepsilon_j$, where $X_j$ incorporates both $O_j^n$ and $A_j$. $\varepsilon_j$ is assumed to be i.i.d. mean-zero and captures unobserved neighborhood attributes.[12]

The price of land, $P_j$, is assumed to equal the average 1992 land assessment per square foot[13] annualized following Poterba's [20] approach for incorporating tax and appreciation effects. In the model, the privately capitalized open space component $O_j^p$ is captured by including the average distance from a home in neighborhood $j$ to a protected parcel of open space. The neighborhood or endogenous component of open space, $O_j^n$ equals the percentage of the land area in zone $j$ which is undeveloped. Permanent income and heterogeneity in the taste for the locational attributes are introduced through $y_i$ and $\alpha_i$ respectively. The distribution parameters for these variables are not directly observed and they are assumed to follow a bivariate log-normal distribution.

### 3.2. Supply

Price-induced supply responses are incorporated using an empirical model of the conversion of land from undeveloped to residential use. The estimates from this model provide for each parcel a probability distribution of the reservation price at which the parcel will be converted (see Walsh [21]). Based on these estimates, the land supply function maps neighborhood specific

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10 Hanemann's Eq. (3.21a) is adjusted to control for an index of location specific amenities, $g(O_j^n, A_j)$. The augmentation factor adopted here is given by $1+(O_j^p)^{\lambda}$.

11 To show the link to Cobb–Douglass preferences, take the limit of the indirect utility as $\eta \to -1$ and $\nu \to 1$.

12 As is required within the Epple–Sieg framework, this preference specification satisfies the conditional single crossing property in income and tastes for the location specific amenity index. Thus it implies stratification in terms of the augmented price and the level of $G$. In typical applications single crossing implies sorting across products/zones by quality and price. Here the sorting occurs in quality and augmented price, $\widetilde{P} = \frac{P_j}{1+(O_j^p)^{\lambda}}$. For a further discussion of single-crossing in this context see Epple and Sieg [15]. The slope of indifference curves in the $\{G, \widetilde{P}\}$ plane are given by:

$$M(\alpha, y, B, G, \widetilde{P}) = \frac{d\widetilde{P}}{dG}\bigg|_{V=\bar{V}} = \frac{\alpha(\frac{1}{1-\nu}y^{1-\nu} - \frac{1}{1+\eta}B\widetilde{P}^{\eta+1})}{GB\widetilde{P}^{\nu}} \tag{3}$$

$M(.)$ is strictly increasing in $\alpha$ and $y$ over the plausible range of parameter estimates.

13 Empirically, the need to identify land prices, as opposed to prices for the lot-house bundle is problematic. As is discussed in Bates and Santerre [7] the use of assessed land values to determine land prices has the advantage of accounting for locational differences in the value of land. Additionally, in contrast to the use of agricultural land values or data on the sales of undeveloped lots, this approach provides a complete coverage for land values in the county. However, this complete coverage comes at the cost of using the judgment of County assessors in valuing the land and will incorporate any biases associated with this process.

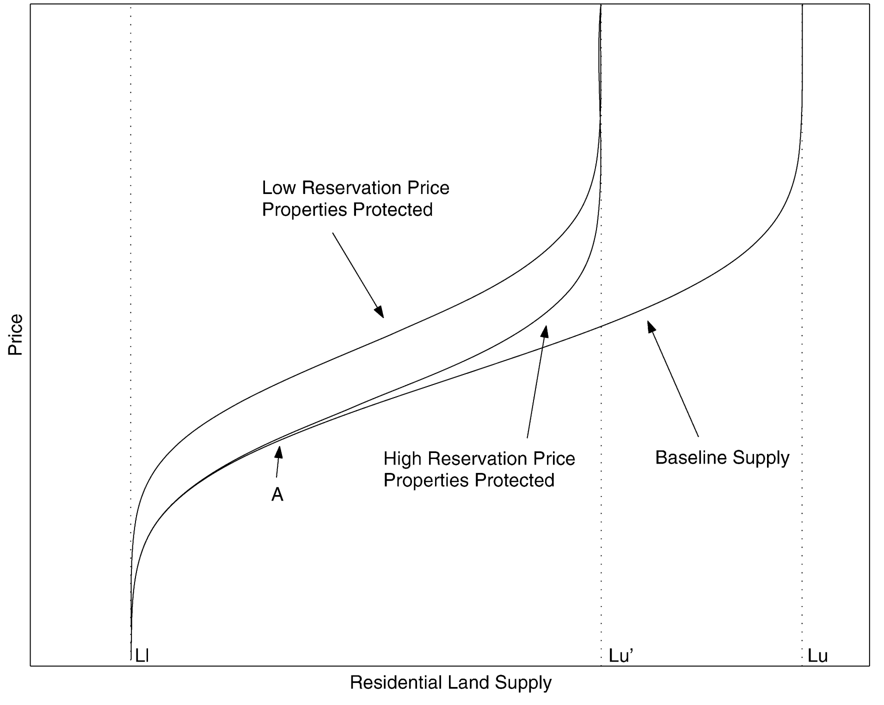



Fig. 1. Impact of land protection on residential land supply model.

residential land prices $P_j$ to the supply of residential land in each neighborhood $S_j$ following Eq. (4).

$$S_j(P_j) = \bar{L}_j + \sum_{k \in j} F_{kj}[P_j] * \text{AREA}_{kj} \tag{4}$$

$F_{kj}[.]$ is the CDF for the reservation price of parcel $k$ in zone $j$, $\text{AREA}_{kj}$ is the area of parcel $k$ and $\bar{L}_j$ is the area of land in residential use in neighborhood $j$ as of 1984.[14] Figure 1 presents a graphical representation of Eq. (4) under the assumption of a logistic distribution of reservation prices.

Figure 1 also illustrates how government purchases of land affect supply in the market. New land protection has two effects on supply. First, protection reduces the aggregate supply of land available for residential development from $Lu$ to $Lu'$. In addition, depending on the distribution of reservation prices for the protected parcels, removal of parcels from the land market will cause a displacement of the supply curve. The distribution of the reservation prices of parcels identified for protection under each of the different policies will depend on the attributes of the parcels selected for protection. Figure 1 describes how two policies for protecting an identical acreage of land can have different effects on supply. The first policy results in purchases of parcels with relatively low reservation prices while the second policy purchases parcels with high reservation prices. The second policy will have little effect on the land market until the demand reaches point $A$ while the first policy has an impact as soon as demand increases above $L_l$. This example

[14] In the land market equilibrium model, land developed prior to 1984 is treated as irreversibly developed.

demonstrates how heterogeneity in the characteristics of land parcels protected under differing policies can affect the supply response.

### 3.3. Equilibrium

The land market outcome described by individual choices of location and lot size $\{j_i^*, d_i^*\}_{i\in I}$ arises from the interaction of supply and demand in the residential land market. Neither side of the market internalizes the externalities that arise through the neighborhood character component of the metropolitan landscape, $O_j^n(\{j_i^*, d_i^*\}_{i\in I})$. This externality complicates characterization of equilibrium. As consumers respond to exogenous changes in the market, not only will prices adjust, but changes in their locational choices and land demands will lead to new values for the endogenous open space measures. These open space changes then in turn imply revised consumer land demands.

Given a finite set of location choices, $J$ and households $I$, a Nash equilibrium is characterized by Eqs. (5)–(8).

$$\forall i \quad j_i^* = \arg\max_{j\in J}\left\{v\left[P_j, O_j^p, O_j^n, A_j \mid y_i, \alpha_i\right]\right\}, \tag{5}$$

$$\forall i \quad d_i^*\left(P_j, O_j^p \mid y_i, \alpha_i\right) = \frac{1}{1+(O_j^p)^\lambda} B \widetilde{P}_j^\eta y_i^\nu, \tag{6}$$

$$\forall j \quad \overline{L}_j + \sum_{k\in j} F_{kj}[P_j] * \mathrm{AREA}_{kj} = \int_{\{y_i,\alpha_i\}\in C_j} d_i^*\left(P_j, O_j^p \mid y_i, \alpha_i\right) \mathrm{d}F_{y\alpha}(y_i, \alpha_i), \tag{7}$$

$$\forall j \quad O_j^n = O_j^n\left(\{j_i^*, d_i^*\}_{i\in I}\right) \tag{8}$$

$C_j$ is the set of $y_i, \alpha_i$ realizations for which community $j$ is the optimal community, and $F_{y\alpha}$ is the cumulative density function for $y_i, \alpha_i$ pairs.

Equation (5) insures that all households choose their optimal neighborhood and, conditional on choosing said neighborhood, Eq. (6) requires each household to consume their optimal lot size, as given by Roy's identity. Equation (7) requires that the residential land supply in zone $j$ equals the aggregate demand in zone $j$. Finally, Eq. (8) states that the level of neighborhood open space in zone $j$, $O_j^n$, is determined endogenously as the percentage of all of the land in zone $j$ that is not developed in equilibrium.

### 3.4. Model limitations

A strength of the proposed model is that its parsimonious nature facilitates direct estimation of the components of the simulation model in a framework that is consistent with the simulation model's underlying assumptions. Of course, this tractability comes at a cost. The key limitation of the model is the vertical and homogeneous treatment of communities. For instance, a key determinant of location choice is job accessibility. One would expect individuals to assign differing measures of job accessibility to the same location depending on work location. In the model, because communities are vertically differentiated, all households must perceive the same measure of job accessibility for each location.

Further, different locational amenities are likely associated with differing spatial scales. By defining discrete zones over which these amenity levels are assumed constant one runs the risk of averaging out important differences. One possible solution would be to define very small zones and thus average over much smaller areas. Unfortunately this approach runs into issues of tractability. In the end, the chosen approach represents a trade-off between richness of specification and tractability. As is discussed below, the model fits the observed data quite well—suggesting that the required parsimony does not come at too high a cost.

## 4. Estimation of household preferences

The analysis extends the Epple–Sieg framework for estimating preferences based on the properties of locational equilibrium by allowing open space to have two effects on individual preferences.[15] Access to protected public land, $O^p$, influences demand for lot size directly, while the neighborhood quality measure $O^n$ acts at the extensive margin, affecting community choice. The specification allows for heterogeneous tastes for the index of public goods $G$ via the taste parameter $\alpha_i$. The estimation strategy recovers four sets of parameters: the parameters of the joint distribution of income and tastes for location specific amenities; the parameters of the indirect utility function; the augmentation parameter $\lambda$; and, the parameters of the public good index.

Following Epple and Sieg, a two-stage simulation-based procedure is used to estimate the model's parameters. The first stage recovers the heterogeneity parameters, indirect utility parameters, and the augmentation parameter by matching the models predictions to the observed 25th, 50th, and 75th parcel-size quantiles in each zone. This is done as follows. The price per unit land in each zone is fixed at its observed 1992 value.[16] For a given set of parameter values, the model is solved for the equilibrium allocation of households across zones, and the associated optimal equilibrium parcel purchases by each household. Values of the public good index, $G_1, \ldots, G_j$, are chosen so that the number of households choosing each zone in the computed equilibrium equals the observed number of households in each zone. The predicted quartiles of the equilibrium parcel sizes within each zone are then calculated. The difference between these predicted quartiles and the observed quartiles yields a vector of $JX3$ distances that are weighted

[15] The approach taken here is related to two additional empirical approaches to estimating household sorting models that have been developed recently. Bayer [22] extends the differentiated product model of Berry et al. [23] to estimate an equilibrium sorting model of residential and schooling decisions of households with elementary school-aged children in California. In a more recent application of this approach, Bayer et al. [24] use restricted access census data that links household demographics to characteristics of the actual residence and census block to estimate a model of household choice in the greater San Francisco Bay area. Their analysis adopts a probabilistic notion of housing market equilibrium over a fixed set of houses with fixed characteristics. In equilibrium, for each house, the sum across individuals of the probability of occupying said house is equal to one. The second approach is based on the computable equilibrium model of Nechyba [25] and has been developed by Ferreyra [26]. She estimates an empirical model that jointly determines school quality and household residential and school choices within an economy composed of multiple public school districts and private schools. Equilibrium under Ferreyra's model involves assignment of households to a fixed stock of houses with fixed characteristics such that each house is occupied and no household can be made better off relocating to a different house.

Each of these two approaches are variants of the basic assignment model which treats the quantity and characteristics of the housing stock in each region as fixed. This assumption is not problematic for the types of analysis undertaken by Bayer et al. [24] and Ferreyra [26]. However, because of the critical connection between changing development patterns and open space provision, the assumptions regarding the supply side of the equilibrium model makes these approaches inappropriate for the current analysis.

[16] For estimation, zone prices and populations are assumed to observed without error. Because the populations are taken from a complete census of the housing lots in the County, the population assumption is innocuous. The price assumption, while much stronger, is necessary for the tractability of the model. In particular, this allows for the household preference and distribution parameters to be estimated without regard to the land supply function which only comes into play in computing counterfactual land market equilibria.

to form the econometric objective function. The weights in the objective function are chosen under the assumption that differences in fit between the computed and empirical quartiles arise from sampling error in the construction of the observed quartiles. Estimation entails a non-linear search for the set of parameter values that minimizes the objective function.[17] The second stage treats the public good index estimated in the first stage as the dependent variable in an equation to estimate coefficients on observed zone level attributes (including privately held open space) that influence the level of public good provision.

## 5. Data

The study area for this project is Wake County, North Carolina. The county includes the state capital and a portion of the Research Triangle Park. It has experienced rapid development and contains significant areas of protected and unprotected open space. The empirical model requires dividing the county into a set of spatially distinct choice alternatives. This task was implemented by aggregating up approximately 700 small spatial units labeled as nodes into 91 discrete zones,[18] that are constructed to be as homogeneous as possible in location specific attributes. The 700+ nodes are defined by the Wake County Public School System to take account of neighborhood and subdivision boundaries in establishing the primary and secondary school assignments for the consolidated county-wide school system. The nodes were aggregated to produce neighborhood zones whose boundaries reflect the intersection of local jurisdictional boundaries, major roadways and school attendance boundaries. Figure 2 shows the boundaries of the 91 zones.

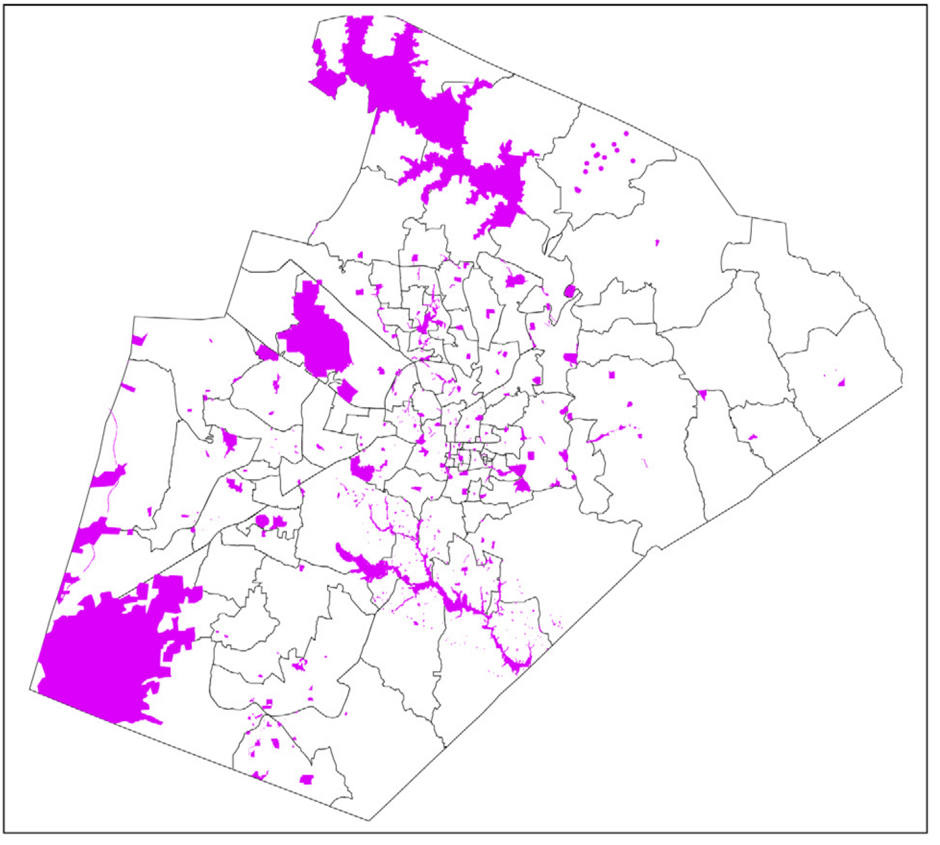
Information on lot size, 1992 tax assessments (distinguished into separate land and structure assessments) and current land use were assembled from GIS parcel data and tax records supplied by the Wake County Assessor's Office. This data set contains information on approximately 230,000 parcels of land in Wake County. Collectively the parcels cover 510,677 acres of land and account for 95% of the area of Wake County, with the remaining 5% comprised mainly of roads and road right of ways. Each parcel is identified as having one of 24 land use codes. Based on these codes, each parcel is placed into one of the 5 categories presented in Table 1.[19]

The endogenous or neighborhood component of open space, $O_j^n$ is proxied for using the percentage of each zone's total land area which is in open space. This measure is comprised of a mixture of publicly protected land and privately held land in open space uses such as agriculture. The second measure, $O_j^p$, captures the average distance to protected open space for each home in a given zone. In order to construct this measure for each zone, a unified GIS description of more than 450 individual parcels of protected open space in Wake County was assembled from data provided by the Army Corps of Engineers, North Carolina Department of Environment and Natural Resources and local planning agencies. The shaded areas in Fig. 2 depict these protected parcels. ARCVIEW was used to calculate the distance from each land parcel to the nearest one of these 400+ protected areas. Finally, these measures are linearly transformed so that $O^p \in \{0, 1\}$ and the zone with the largest average distance has a measure of 0 and the zone with the shortest

[17] A technical appendix providing the details of the estimation is available from the author.

[18] Throughout the paper, the terms zone and neighborhood are used interchangeably.

[19] Privately held open space is comprised of the following land uses: agricultural uses, vacant, cemetery, golf course, single family residential greater than 10 acres, and all parcels that were developed after 1992.



Shaded areas represent parcels of protected open space.

Fig. 2. Map of 91 zones and protected open space.

Table 1
Land use summary from parcel maps

| Land use | Acres | Percentage of total |
|---|---|---|
| Business/Commercial | 16,694 | 3.27% |
| Residential | 102,897 | 20.15% |
| Protected open space | 81,084 | 15.88% |
| Privately held open space | 295,566 | 57.88% |
| Other | 14,436 | 2.83% |
| Total | 510,677 | 100% |

average distance has a measure close to 1.[20] This approach creates a measure that is increasing in the level of amenity conveyed.

[20] Specifically, $O^p = -\frac{\text{average distance}_j - \text{max average distance}}{\text{max average distance}}$.

Table 2
Summary statistics for 91 residential zones

| | Mean | Std. Dev. | Min. | Max. |
|---|---|---|---|---|
| Average assessed lot price (\$ per ft$^2$) | 0.165 | 0.128 | 0.013 | 0.553 |
| Lot expenditure 25th quartile | 15741.44 | 15630.43 | 1742.4 | 88862.4 |
| Lot expenditure 50th quartile | 23450.6 | 23254.7 | 3920.4 | 131551.2 |
| Lot expenditure 75th quartile | 43703.6 | 78702.25 | 5662.8 | 652528.8 |
| Residential lot count | 1005.978 | 757.86 | 3 | 3026 |
| Population share | 0.011 | 0.008 | 0 | 0.033 |
| Ratio of commercial to residential acres | 0.2428 | 0.3225 | 0 | 1.9812 |
| Percent of zone in open space ($O^n$) | 0.61 | 0.215 | 0.17 | 0.965 |
| Average distance to protected open space (feet) | 3004.69 | 3065.06 | 320.31 | 20326.39 |
| Protected open space measure ($O^p$) | 0.856 | 0.15 | 0 | 0.983 |
| Average distance to CBD (feet) | 40298.07 | 25625.36 | 2018.619 | 96833.3 |

Table 3
Values for Poterba calculation

| | | |
|---|---|---|
| $\tau$ | owner's marginal tax rate | 15% |
| $\tau_p$ | property tax rate (varies) | 0.66–1.30% |
| $i$ | interest rate | 8.692% |
| $\beta$ | risk premium | 4% |
| $m$ | maintenance | 2% |
| $\pi$ | home appreciation rate | 2.886 |

Additional data were collected to control for other location specific amenities.[21] To control for commuting distances, the average distance to several employment centers, including the state capitol and Research Triangle Park (RTP) was calculated for each zone. Additionally, indicator variables for each of the 13 local jurisdictions are used to control for other unobservable attributes. Summary statistics for the 91 zones are contained in Table 2.

Finally, the model requires that land prices be converted to annual rental values. Using the calculation suggested by Poterba [20], annualized rents are given by Eq. (9).

$$R = \big[(1-\tau)(i+\tau_p)+\beta+m+\delta-\pi\big]P_H. \tag{9}$$

The specific variables and their values are given in Table 3.

## 6. Estimation results

I begin discussion of the empirical results by considering how well the first stage of the structural model fits the data. The three panels of Fig. 3 report both the actual (circles) and predicted (line) lot size quartiles for the 91 zones with the zones organized from lowest to highest median

[21] Omitted from the analysis are variables measuring school quality and crime, both of which could potentially be important for household location choice. Because this research is focussed on Wake County which is itself one unified district, resources can be expected to be uniform across schools. A different approach would be to focus on school attendance zones within the unified district. However, when included in the analysis, measures of individual school quality were never found to be significant. This is likely because the presence of magnet schools and frequent changes in school assignments further serve to weaken the link between location choice and school quality. Crime is a second concern. Unfortunately, the only data available at a sufficiently disaggregated level is for homicides. Due to the small number of homicides in the County and their lack of spatial variation, crime data are excluded from the analysis.

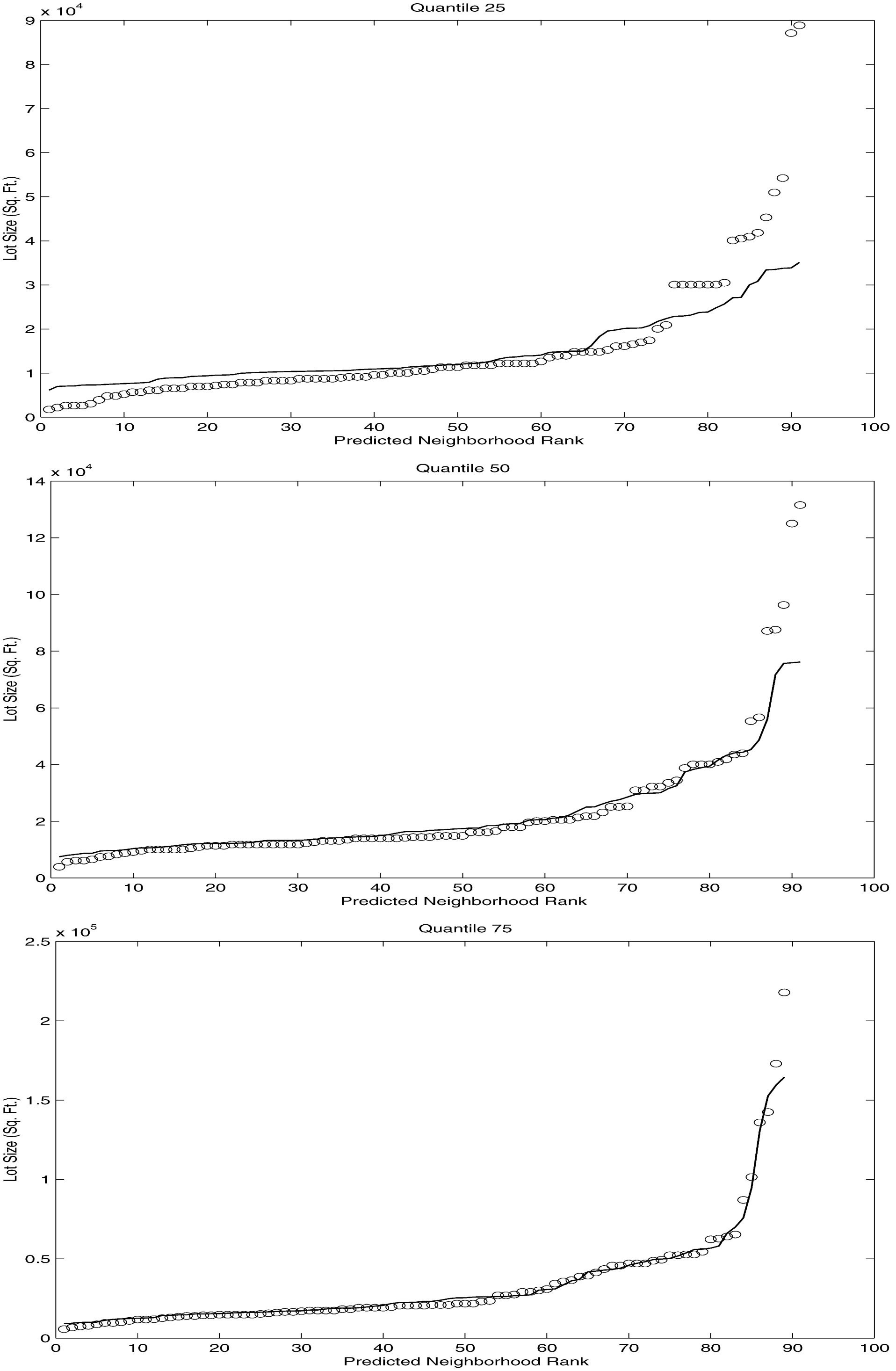



Fig. 3. First stage goodness of fit.

Table 4
Household location model's first stage parameter estimates

| | Parameter estimate | Estimated asymptotic S.E. |
|---|---|---|
| Variance of $\ln(\alpha)$ | 0.2981 | (0.0033) |
| Variance of $\ln(y)$ | 0.2823 | (0.0061) |
| Price elasticity ($\eta$) | −0.6174 | (0.0166) |
| Income elasticity ($\nu$) | 0.7474 | (0.0844) |
| Demand parameter ($B$) | 1.5545 | (0.0051) |
| $\alpha$–$y$ correlation ($\rho$) | −0.0196 | (0.004) |
| Augmentation parameter ($\lambda$) | 21.8257 | (0.0032) |

lot size.[22] Given the parsimonious nature of the model, the fit is fairly tight. The figure shows that the model accurately predicts lot size at the middle of the distribution, and does less well in the tails—over predicting lot size in the zones with smaller lots (especially at the 25th quartile) and under predicting lot size in the zones with the largest lot sizes.

The estimated first stage parameters for the household location model are reported in Table 4.[23] Where it is possible to make comparisons with the existing literature they fall within the range of past estimates. Because the variance of income is identified from the distribution of housing expenditures, this measure more closely approximates the variance of permanent income than the variance of current income. As a result, the estimated variance of the log of income, $\ln(y)$, is below estimates of the variance of current log-income derived from fitting log-normal distributions to current income.[24] The estimated price elasticity of $-0.62$ is consistent with Sirmans and Redman [27] who compare price elasticities for 52 different urban areas for the years 1967, 1971 and 1975.[25] While significantly different from 0, the estimate of the correlation parameter $\rho$ suggests little correlation between tastes for location specific amenities and permanent income.[26]

Finally, the estimated value of 21.83 for the augmentation parameter $\lambda$ is consistent with the a priori expectation that private lot consumption and proximity to protected open space are substitutes. Figure 4 illustrates how the average distances to protected open space (on the $x$-axis) translates into values for the price augmentation factor $1 + (O_j^p)^\lambda$ (on the $y$-axis). As the average distance moves from half a mile to one quarter of a mile, the augmentation factor increases by 17.5%. Evaluated at the mean (across zones) of the 50th percentile of lot expenditure ($23,451) this change in the augmentation factor roughly corresponds to a one time incremental willingness to pay for the change in average distance of $4104. This estimate is less than that of Correll et al. [3]. Using their marginal willingness to pay measure of $4.20 per foot of walking distance

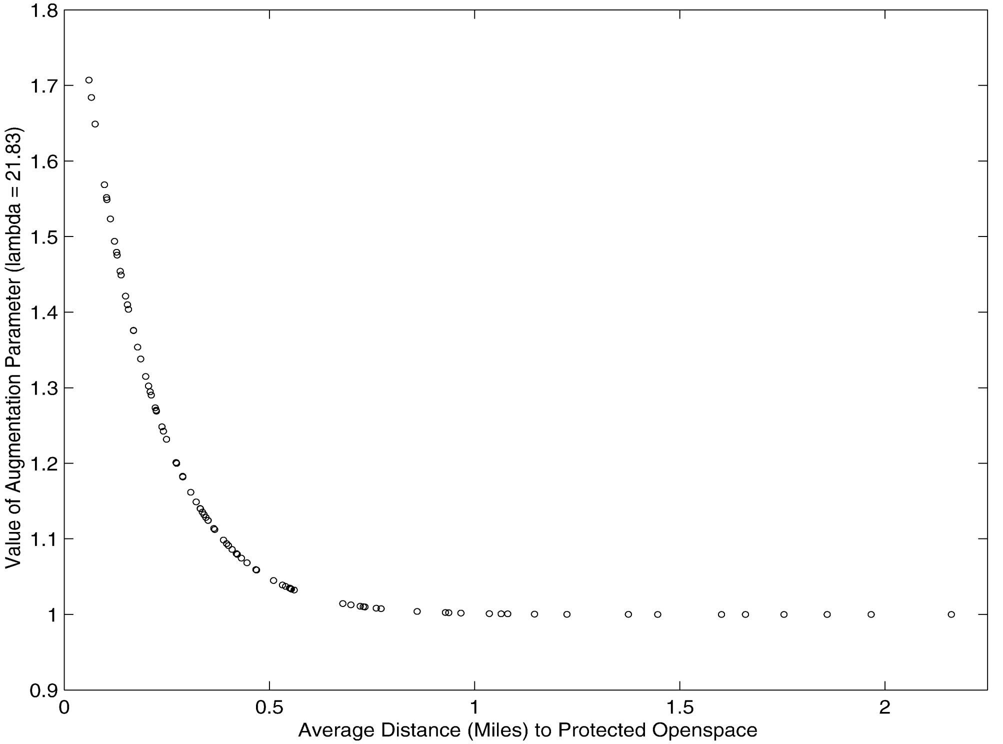
[22] To allow for better scaling the two zones with the largest lot sizes are excluded from the third panel of the figure. As in the 25th and 50th quartile, the model under predicts the 75th quartile lot size for these two zones.

[23] Note: the small standard errors on the first stage coefficients are a function of the large number of housing unit observations (91,544) that are used to compute the observed lot quartiles in each zone.

[24] For example, Epple and Sieg [15] estimate 0.755 as the variance of ln current income in the Boston Metro area.

[25] While the literature has not identified income elasticities of demand for residential land, Polinsky [28] provides estimates of housing demand income elasticities of 0.75.

[26] It is important to note that this result only applies to the correlation of *unobserved tastes* and *income* and reflects the observed distribution of income types across the neighborhoods. The parameter estimates still imply, as would be expected, that demand for the public good is increasing in income.




For better scaling, one observation corresponding to an average distance of 3.8 miles has been omitted.

Fig. 4. Effective price function—household location model.

to protected open space leads to an estimate of $12,250 as the value of decreasing the distance to protected open space for a given house by a quarter mile.[27]

In addition to the parameters discussed above, first stage estimation recovers the index of local amenities, $G_j$, for each zone. The percent open space measure enters the model through this index. To recover the specific role of open space in the indirect utility function it is necessary to decompose the G-index into its component parts. To facilitate this decomposition, the relationship between the G-index and the locational attributes is assumed to follow a semi-log function, $\ln G_j = X_j'\gamma + \varepsilon_j$.

Two normalizations are required to identify the model's second stage. First, the decomposition of $G_j$ is assumed not to include an intercept. Second, the coefficient on the percentage open space measure is normalized to 1. A GMM procedure is utilized to estimate the model's second stage parameters. The parameter vector is comprised of the parameters of the index $\gamma$, $\ln G_1$ and $\exp(\mu_{\ln\alpha})$. The moments used in estimation are then of the form in Eq. (10).

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)X_j'. \tag{10}$$

[27] The consumer price index was used to convert this figure 1992 dollars.

The set of explanatory variables $X$ includes the percentage of the zone in open space. The square of this measure is also included to allow for non-linear open space effects. It is to be expected that this measure is correlated with the error term $\varepsilon$. However, Eq. (10) can be estimated using instrumental variables with a vector of instruments $Z'_j$ that includes all of the elements of $X$ except the open space percentage measures and additional variables assumed to be correlated with open space percentage, but not correlated with $\varepsilon$. The Instrumental Variables Estimator is defined by Eq. (11).

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)Z'_j. \tag{11}$$

The results for five second stage specifications are presented in Table 5. Models I–III do not instrument for the open space percentage measures while Models IV and V utilize a set of soil-based predictors of the suitability for residential construction and value in non-developed use as instruments for the open space percentage measures (these measures are assumed to affect only the supply side of the land market).[28] In addition to the coefficients on the explanatory variables, the table reports the estimate of $\ln G1$ and the exponent of the mean of the log of $\alpha$ which is labeled $K$ in the table.

Model I includes only the open space measure, with the coefficient on open space percentage normalized to one. The negative coefficient on the quadratic term implies that $G$ is increasing in open space percentage over an initial range of values and then beyond some critical point a negative relationship holds.[29] The values for this critical point are included in the table. For the simple specification of Model I, the value of this critical point is 33%. Model II adds as an explanatory variable the percentage of each zone that is in a business or commercial usage. This measure is treated as exogenous. The coefficient on this variable is positive in all four

Table 5
Decomposition of augmentation model's G-index

| Model | Open space$^2$ | Pct. bus/com | Mean emp. dist. | $\ln G1$ | $K$ | Jur. Ind. | I.V. | Critical point |
|---|---|---|---|---|---|---|---|---|
| I | −1.5221 | | | −0.5839 | 0.04733 | | | 0.3285 |
| | (0.2638) | | | (0.3289) | (0.0187) | | | |
| II | −1.6472 | 0.6986 | | −0.7311 | 0.0388 | | | 0.3035 |
| | (0.3607) | (0.4124) | | (0.4460) | (0.0177) | | | |
| III | −1.4892 | 0.6032 | −0.0439 | −1.3758 | 0.0274 | | | 0.3357 |
| | (0.2461) | (0.3735) | (0.0151) | (0.5210) | (0.0090) | | | |
| IV | −1.5255 | 0.2628 | −0.0014 | −0.4159 | 0.0675 | | × | 0.3277 |
| | (1.0205) | (0.5698) | (0.0082) | (1.0058) | (0.1021) | | | |
| V | −1.5687 | 0.2447 | −0.0001 | −0.4242 | 0.0792 | × | × | 0.3187 |
| | (0.9456) | (0.4785) | (0.0069) | (0.9500) | (0.1089) | | | |

[28] Instruments include measures of agricultural productivity, suitability for development, septic system potential and the presence of soils associated with wetlands. Of course, if these soil characteristics have a direct effect on unobserved neighborhood characteristics that go beyond development potential then the estimates will still be biased. See Walsh [21] for details of the construction of these variables.

[29] Several additional models, including cubic, quartic and spline models, were run to test the sensitivity of the shape of this relationship to this functional form. The results of this analysis suggested no qualitative difference between the simple quadratic form and the more complicated models.

specifications, but is statistically insignificant, in all but Model III which controls for distance to employment centers but does not instrument for the endogeneity of open space percentage. Models III–V incorporate the mean distance to eight different employment centers as explanatory variables.[30] All three of these models result in the expected negative coefficient on this variable. However, the coefficient is not significant for instrumental variable estimates.

With the endogeneity of each zone's open space percentage a potential concern, Models IV and V instrument for open space percentage. Model V also includes indicator variables for local jurisdictions. The sign on Business and Commercial development remains consistently positive but insignificant across the models. The coefficient on the employment center variable has the expected sign in all models but becomes insignificant once instruments for open space percentage are included.

From the perspective of the policy simulations, the most important parameter in the second stage decomposition is the coefficient on the quadratic open space term. This coefficient is stable and significant across the specifications—in all specifications except Model IV the coefficient passes a two-tailed significance test at the 10% level. The coefficient values range from a low value of $-1.65$ to a high value of $-1.49$. These values correspond to critical points in the range of 0.30 to 0.33. The estimates suggest that local amenities are maximized when the level of open space provision lies between 30 and 33 percent of a given neighborhoods land area. It is interesting to note that due to the relatively rural nature of most of Wake County, a majority of the County's zones experience open space percentages that are in excess of this bliss point. Thus, for many locations, utility is increasing in $O^p$ and decreasing in $O^n$. This result appears to reflect a trade-off between open space land uses and developed land uses. In other words, in the rural portions of the county, households would be willing to give up land in open space use for developed amenities. However, conditional on the level of development, households view additional access to protected open space as being unambiguously positive.

Because it includes instruments for the open space measures and indicator variables for the local jurisdictions, Model V is selected for use in the general equilibrium policy simulations.

## 7. Policy simulations

Three different policies are analyzed using the model, two land/development rights acquisition policies and one development restriction policy. The policy simulations are designed to replicate direct acquisition and growth boundary/zoning polices. They "reconstruct history" by evaluating what would the character of the county have been in 1992 had it been possible to change either the set of protected land parcels or land policies as of 1984.

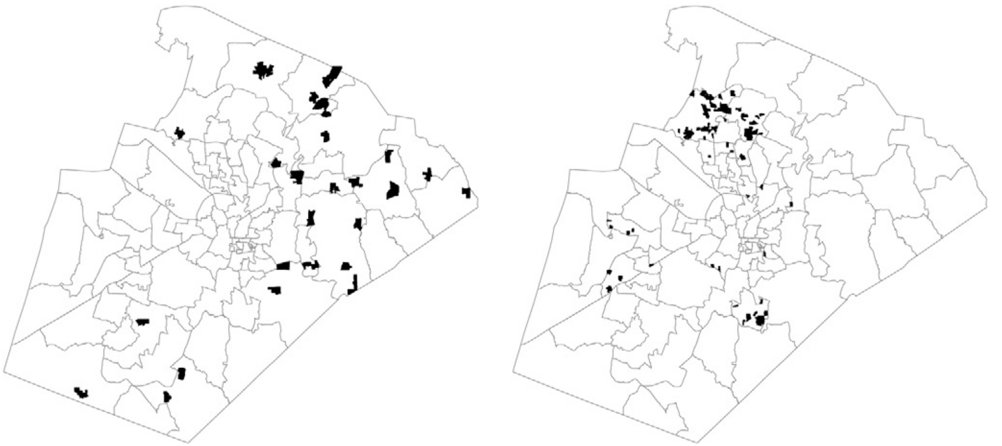
### *7.1. The policies*

In November of 2001, Wake County passed a bond initiative designed to raise \$15 million for land protection through direct acquisition and the purchase of development rights. This recent policy is used to scale the two land acquisition policies. Each policy prioritize parcels for protection in different ways. Policy I reflects a goal of preserving agricultural land and open space at the urban fringe. Policy II focuses on protecting open space in the more densely populated portions of the county.

[30] See Walsh [21] for a discussion of the identification of these employment centers and for sensitivity analysis regarding the use of differing measures of access to employment centers.

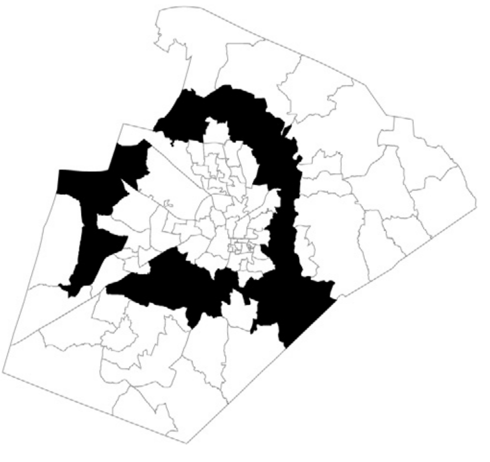
Land is assumed to be protected by both fee simple transfers and the purchase of development rights (PDR).[31] Derr and Dhillon [31] suggest that 2/3 to 3/4 of market value is accounted for by a property's development potential. Based on these estimates, the analysis assumes $15 million available for protection will protect approximately $22.5 million (i.e. 3/2 of $15 million) worth of residential land. The parcels protected under the two land protection policies are shown in Fig. 5.

Systematic rules are adopted for developing the policies that are evaluated (see the first four rows of Table 7 for a summary of the implementation of these policies). The land protection



Land protection policy I Land protection policy II

Shaded areas represent the additional protected land under each policy.



Growth ring policy

Shaded areas represent zones where development is frozen at 1984 levels.

Fig. 5. Policy simulations.

31 An overview of easement valuation issues is contained in Wiebe and Tegene [29]. For specific discussion of the issues associated with the value of the option to develop see Tegene et al. [30].

policies are realized in the model by removing the newly protected parcels from the set of potentially developable parcels in the land supply functions and recalculating the open space access measures to reflect the additional parcels of protected open space. These calculations are then input into the model and new equilibrium values for household location choices, neighborhood land prices and neighborhood open space percentages are identified.

Consistent with a goal of protecting large contiguous areas of open space, policy I protects the largest undeveloped parcels in the county (irrespective of location within the county) that are in forested or agricultural use as of 1984. Starting with the largest available parcel and then moving to the next largest parcel and so on, parcels are set aside for protection until the 27 largest available undeveloped parcels with a total worth of approximately $25 million and distributed across 16 zones have been protected.[32] The average parcel size under this policy is 365 acres. A total of 9859 acres are protected. The average land price under this policy is $2208 per acre. Policy II mimics policy I except that protection activities are restricted to the more densely populated zones of Wake County. Implementation is identical to policy I except that only parcels located within the 45 most densely developed zones are eligible for protection. Under this policy, 82 parcels with an average size of 51 acres are protected in 15 different zones for a total of 4176 acres. The average land price for protected parcels is $5340 per acre.

In contrast to the direct acquisition of open space, many local jurisdictions attempt to control the pattern of privately held land uses through the implementation of large scale zoning restrictions, such as urban growth boundaries. The final policy experiment is designed to explore the equilibrium adjustments that may be associated with these types of market interventions. Consistent with this regulatory approach, the policy experiment incorporates a markedly larger scale of intervention than is contemplated by the two land protection policies and does not lead to the creation of any new publicly owned open space. Thus, while it provides insight into the impact of these zoning policies, it is not directly comparable to the two land protection policies.

To implement the policy, residential development in a selected set of zones in Wake County is frozen at 1984 levels. In the simulation, this is accomplished by fixing the model's land supply function for these zones. Because this policy is designed to replicate zoning or growth restrictions there is no increase in access to publicly owned open space, $O^P$. The policy rule adopted for the experiment is designed to approximate a typical growth ring zoning policy. It freezes development in all zones with a 1984 density less than 0.1 residential households per acre that abut the higher density zones that lie in the core of the county (identified in Fig. 5).

### 7.2. *Computing the counterfactual land market equilibrium*

The Land Market Equilibrium Model merges the estimated household preference model with zone specific land supply functions to yield a computable GE model of residential land markets.

The supply side of the model is aggregated from individual parcel data as described in Section 2. Empirical estimates for the model are taken from Walsh [21] which estimates the probability that an individual parcel will convert from an undeveloped state to residential development over the 1984–1992 time period. The probability estimates are based on a two-step logit model which is a simplified version of the approach developed by Nevo [32]. In addition to price, the determinants of conversion include productivity in agricultural use, physical characteristics

[32] Land prices are based on the 1992 Wake County Land Assessment.

that describe the suitability for development, environmental constraints on development, local jurisdiction dummies, and a zone specific constant.

To compute new land market equilibria associated with the three policy scenarios, the basic algorithm is as follows. First, the vector of zone specific endogenous landscape amenities (open space percentages) is fixed at an initial level and a vector of prices is identified which clears the land markets.[33] This market clearing process leads to a change in the level of privately held open space in each zone away from the initial level. This occurs for instance when households move into a zone and reduce the stock of private vacant land. To account for this endogeneity, following the land market clearing, new amenity levels are calculated (new levels of the public good index $G$ which account for the endogenously determined open space percentages) for each community. A new vector of land market clearing prices, based on the updated $G$ vector, is then computed. This process is iterated until a fixed point is identified. In practice, this process typically takes approximately 10 iterations.

### *7.3. Baseline equilibrium*

The general equilibrium model assumes that the spatial distribution of households that we observe in Wake county can be perfectly characterized by a Locational Equilibrium arising from the household choice and land supply functions specified above. To provide a baseline for comparison to the three policy simulations, the G.E. computation is performed using the observed level of endogenous landscape amenities (open space percentages) as starting values and holding the distribution of protected open space fixed. If the parameter estimates, structural specification, and Nash equilibrium assumption are the "true model" that gave rise to the observed actual location choices then this computation should yield equilibrium values for the endogenous open space measure that correspond exactly to the observed values. Calculating this initial equilibrium provides an appropriate baseline with which to compare the equilibrium outcomes under the various policy scenarios. The baseline equilibrium reasonably replicates the observed distribution of open space. In all but 4 of the zones, the computed baseline general equilibrium open space percentages were within 20 percentage points of the actual observed value with the majority differing by much less.

### *7.4. Welfare measurement*

One goal of the analysis is to evaluate the welfare implications of the different policies. In the context of the model, welfare measurement must account for four distinct adjustments (relative to the baseline equilibrium) that are associated with the counterfactual equilibria. First, under the counterfactual, household $i$'s location choice $j'$ may differ from its original location choice $j^0$. Second, as households relocate and adjust their optimal lot-size, the open space percentages in each zone adjust, leading to new levels of the public good index. These new levels are denoted by $G'$. Because $O^n$ enters the G-index in a quadratic form, the direction of the change in $G$ depends on the change in $O^n$ and the initial level of $O^n$. Above the critical point of 32% increases (decreases) in $O^n$ reduce (increase) the level of $G$. Below the critical point, the relationship is reversed. Third, household location adjustments and the supply effects associated with the additional land protection cause prices (augmented prices) to adjust from $P^0$ to $P'$ ($\widetilde{P}^0$ to $\widetilde{P}'$). Finally,

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[33] The procedure for identifying the market clearing vector of prices parallels the numerical method used to solve for the equilibrium value of the $G$ vector in the estimation of the household model. For more details see Walsh [21].

because of the model's implicit treatment of households as renters, price increases (decreases) translate to transfers away from (to) households to (away from) absentee landlords. To account for this transfer, the property value change per household is included in the general equilibrium benefit measure. Specifically, the change in capitalization is equal to $(P'_{j0} - P^0_{j0}) * \text{Lot Size}^0_i$.[34]

To consider the respective impacts of these effects on the measured general equilibrium benefit, it is helpful to decompose the G.E. benefit measure as in Eq. (12):

$$\begin{aligned}\text{Benefit}_i = {} & \big[y_i - e_i\big(\widetilde{P}\big(O^{p'}_{j0}, P^0_{j0}\big), G^0_{j0}, U^0_i\big)\big] \\ & + \big[e_i\big(\widetilde{P}\big(O^{p'}_{j0}, P^0_{j0}\big), G^0_{j0}, U^0_i\big) - e_i\big(\widetilde{P}\big(O^{p'}_{j'}, P'_{j'}\big), G'_{j'}, U^0_i\big)\big] \\ & + \text{Change in Capitalization}_i. \qquad (12)\end{aligned}$$

The first term in Eq. (12) is household $i$'s Hicksian willingness to pay for the new level of protected open space $O^{p'}_{j0}$ assuming no equilibrium adjustments. $y_i$ is household $i$'s income, $e_i(.)$ is the expenditure function for household $i$, $G^0_{j0}$ is the pre-adjustment level of the amenity index in household $i$'s initial zone, and $U^0_i$ is the initial level of utility for the household. $\widetilde{P}(O^{p'}_j, P^0_j)$ is the augmented price in household $i$'s initial zone, evaluated at pre-adjustment prices accounting for the zone's change in $O^p_j$ which results from the new land protection policy (see Table 7 where this second term is labeled "Partial CV (no adjustment)").[35] The second term in Eq. (12) is the difference between household $i$'s willingness to pay for the general equilibrium outcome and the partial WTP measure captured by the first term. The final term accounts for transfers to (from) absentee landlords as a result of price changes.[36]

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[34] It is important to note that the model captures only those benefits associated with differential proximity to open space amenities. Benefits such as ecological concerns and ground water protection which are likely to be shared equally regardless of location within the County can not be captured in the model.

[35] All benefit measures are reported in \$ per year.

[36] In defining the change in capitalization to equal $(P'_j - P^0_j) * \text{Lot Size}^0_i$, the above discussion implicitly assumes that the quantity of developed land in each zone is identical under both the baseline equilibrium and the proposed policy. Treatment of parcels that change development state between the baseline and proposed policy is more complicated. For parcels that are driven by market forces from an undeveloped state under the baseline scenario to a developed state under the proposed policy, the appropriate measure is $(P'_j * -r_i) * \text{Lot Size}^0_i$, where $r_i$ is the value of the land in undeveloped use. The value of $r_i$ is unknown, but because the parcel was undeveloped in the baseline case and developed under the proposed policy, abstracting from conversion costs, we know that $P'_j > r_i > P^0_j$. The capitalization in this case is positive and substituting the two price levels for $r_i$ provides upper and lower bounds for the capitalization effect. A symmetric argument holds for parcels which move from a developed state to an undeveloped state. Here the capitalization is equal to $(r_i - P^0_j) * \text{Lot Size}^0_i$ and $P^0_j > r_i > P'_j$. As in the previous case, it is possible to construct upper and lower bounds for the capitalization.

These bounds will hold with certainty for parcels for which the conversion decision is market based. Unfortunately, these bounds do not apply to policy imposed conversion decisions. Specifically, for parcels that are developed under the baseline equilibrium and are forced into an undeveloped state under the proposed policy, because 1984 price data is not available for the analysis, there is no lower bound on the reservation price. Therefore, a price of \$0.00 must be assumed. For the two land protection policy scenarios, the number of parcels forced to an undeveloped state by policy is small relative to the entire sample. Therefore using this approach to identify capitalization for parcels which change development status leads to tight upper and lower bounds. However, under the development freeze policy, development is "reversed" in large sections of the County. Therefore, the impact of assuming a \$0.00 reservation price for these parcels is restrictive leading to an "extreme lower bound" which varies markedly from the upper bound. Under this policy simulation, the upper bound is likely to be closer to the actual capitalization change than is the lower bound.

### 7.5. Zone-specific decomposition of policy outcomes

To illustrate the interactions that occur in the model, consider the impact of the two land protection policies on specific neighborhoods. These Policies have both direct and indirect impacts that affect the new equilibrium. I begin by considering the direct effects. First, the protection of additional parcels in a given zone increases $O^P$, the measure of access to protected open space.[37] This increase makes the given zone more attractive relative to other zones that do not experience an increase in protected open space. Also, because $O^P$ is a substitute for land in household preferences, ceteris paribus, this increase in $O^p$ decreases per household land demand. The immediate impact of the increase in protected open space is therefore to increase the number of households choosing to live in the zone and to decrease the per household demand for land. The impact on price and development levels from these two factors is indeterminant. Second, the increase in protected open space is associated with a decrease in the supply of residential land. In isolation, this supply decrease would be associated with increased prices, a reduction in the number of households choosing the zone and a reduction in per household lot sizes.

The indirect impacts of the land protection policies result from the endogeneity of prices, open space percentages, and the incomes of households located within each zone. As prices adjust to restore equilibrium, increases (decreases) in a given zones price will lead to out- (in-) migration[38] and decreases (increases) in per household land demand. Changes in the endogenous landscape amenity $O^n$ lead to new levels of $G$. All else constant, increases (decreases) in this amenity level will increase (decrease) the number of households choosing to locate in the zone. Changes in $G$ have no direct impact on per household lot demands, but do affect aggregate lot demand at the extensive margin and can lead to changes in both price and the average income of residents living in the zone. The final important endogenous adjustment is the income mix of each zone. As a new equilibrium is established, the income distribution in each zone will change. These changes impact the amount of residential land demanded per household—with increases in a zone's average income leading to increased residential development and prices.

Consider the outcomes in two different sets of zones under Land Protection Policies I and II. Zone '$Aj$' $j \in \{1, 2\}$ is an example of a zone within which additional land is protected under land protection policy $j$ and zone '$Bj$' $j \in \{1, 2\}$ is an example of a zone which does not experience any additional open space protection under policy $j$.

Outcomes for these four policy/zone pairs are presented in Table 6. The top portion of the table reports the changes experienced within each of the four zones. The bottom portion of the table reports results associated with households that were located in each sample zone prior to policy enactment (and may actually choose a location outside of the zone under the counterfactual).

Under policy I, in sample zone '$A1$' the protection of additional open space in and around the zone leads to a 6.3% increase in the augmentation factor from 1.026 to 1.089. As expected, if no adjustments were to occur, this increase in the augmentation factor would result in the zone's residents having a markedly positive WTP for the policy ($66.37 per household). The general equilibrium calculations identify additional changes. First, new location and lot size changes off-

[37] Note: this impact will not necessarily be limited to the zone in which the parcel is protected, but can have a spillover effect to neighboring zones.

[38] The use of the terms in-migration and out-migration facilitate the comparisons between the baseline equilibrium and the equilibrium under the five different policy scenarios. However, it is important to note that these terms should not be taken literally. Instead, they are used to compare the location choices and zone populations under different simulated equilibria which are predicted to develop between 1984 and 1992.

Table 6
Decomposing the policy impacts

| Policy evaluated: | Policy I | | Policy II | |
|---|---|---|---|---|
| Sample zone | *A*1 | *B*1 | *A*2 | *B*2 |
| *Zone Effects* | | | | |
| Initial open space percentage | 86.9% | 22.4% | 63.4% | 75.2% |
| Acres protected | 342.7 | 0 | 931.3 | 0 |
| Initial augmentation factor | 1.026 | 1.301 | 1.079 | 1.096 |
| Change in augmentation factor | 0.063 | 0 | 0.262 | 0.015 |
| Avg. partial equilibrium WTP | $66.37 | $0.00 | $315.10 | $29.02 |
| New open space percentage | 86.9% | 22.3% | 71.4% | 73.5% |
| Change in G-index | 0 | −0.00013 | −0.0679 | 0.0182 |
| Pct. price change | 8.14% | 0.42% | 4.88% | 11.4% |
| Avg. cap. chg. per household (lo) | $91.89 | $13.6 | $73.99 | $240.76 |
| *Household Effects* | | | | |
| Avg. change in G-index | −0.004 | −0.0001 | −0.02867 | −0.00257 |
| Avg. chng. in Aug. price ($/sqft.) | $0.019 | $0.0042 | −$0.156 | $0.099 |
| Avg. G.E. WTP | −$20.67 | −$15.39 | −$48.3 | −$68.44 |
| G.E. benefit per hshld. | $71.22 | −$1.79 | $25.69 | $172.32 |

set the newly protected open space yielding virtually no change in the percent of open space in the zone. Thus, there is virtually no change in the G-index. The increase in protected land shifts up the land supply function for the zone as some parcels are removed from the set of potentially developable parcels. This upward influence on the zone's price combines with the upward demand shift associated with additional protected open space (reflected in the increase in the augmentation factor) leading to an increase in the price level of 8.14%. This price increase is associated with an increase in capitalization in the zone equal to $91.89 per household.[39] To evaluate the WTP of the zone's households for the equilibrium outcome it is necessary to compare the augmented price and G-index level experienced by households under the new equilibrium to the corresponding levels prior to the protection of additional land. Under the policy I equilibrium, due to out-migration, zone *A*1's households on average experience a decrease in their experienced G-index level. They also receive a small increase in experienced augmented price. The net result is a negative willingness to pay for the new policy of −$20.67 per household. Adding this WTP measure to the zone's change in property values yields a benefit estimate for zone '*A*1' under policy I of $71.22 per household per year.

Because under policy I no new open space is protected in or near zone '*B*1', this zone experiences no change in its augmentation factor and there are no partial equilibrium effects. However, in equilibrium, demand for land in the zone increases as additional protection elsewhere in the county pushes households into the zone. This increased demand drives the price of land up and the percent of open space down. Because the original open space percentage was below the critical point, this decrease in open space reduces the level of the G-index for the zone. Under the new equilibrium, on average the zone's initial residents relocate to zones which provide small decreases in the G-index and small increases in augmented price. These changes yield an average G.E. WTP measure for the zone's households of −$15.39. In contrast to zone/policy pair

[39] This is the lower bound estimate. The upper bound estimate is $92.07.

'$A1$', accounting for the change in property values does not completely offset this negative WTP and yields an aggregate benefit measure of −\$1.79 per household.

Additional facets of the G.E. outcome are demonstrated by the impact of policy II on zone '$B2$'. First, even though no land is protected within the zone under this policy, additional protected land near the zone's border yields a direct spill-over effect causing an increase in the augmentation factor and leading to a positive partial equilibrium willingness to pay measure. Under the new equilibrium, demand for land in the zone increases. This increase in demand leads to decreases in the open space percentage. Because the initial open space percentages are greater than the critical point, these open space decreases are associated with increases in the zone's G-index level. This effect is self reinforcing and results in an 11.4% increase in prices in the zone—yielding a positive capitalization change of \$240.76 per household.[40] This large change dominates the G.E. WTP for the zone's households, resulting in an annual benefit per household of \$172.32.

### 7.6. Aggregate policy outcomes

Table 7 presents summary statistics for the changes, relative to the base-line model, for the three different policy scenarios. The results are expressed for the region as a whole on a per household level. The first four rows of the table present the specifics of the two land protection policies. Row four reports the average change in the price augmentation factor under the two land protection policies. The difference in this measure across the two land protection policies demonstrates that the spatial distribution of land protection is important for determining the direct benefit of the policy. Policy II which focuses protection in more densely populated areas and protects many small parcels leads to a greater increase in access to protected open space (averaged across zones).

The fifth table row reports the change in residential development, relative to the baseline. For the two land protection policies there is a reduction in total residential development. However, the reduction in development from land acquisition is much less than one for one. Policy II has the larger reduction in development, but only results in a 0.12 reduction in acres developed per acre protected. A key point to note here is that even though a shift from policy II to policy I more than doubles the amount of protected open space (an increase of over 5000 acres) endogenous adjustments in privately held open space lead to a *net loss* in open space of more than 200 acres under policy I relative to policy II.

In contrast, the development freeze (growth ring) policy leads to much larger changes in development. This is because on average the policy forces households out of low amenity ($G$) low price zones where lot sizes are large into relatively higher priced higher $G$ areas. The net reduction in development under this policy is 2668 acres.

For certain summary statistics such as this change in public good level, it is unclear what is the appropriate unit of observation over which to calculate averages. Averaging across zones holds the zone constant, but due to re-sorting doesn't necessarily reflect the change actually experienced by households initially located in these zones. Averaging across the change experienced by households corrects for this problem, but no longer holds the zone constant. This distinction is most important for the change in public good levels. Row eight of the table reports the average across zones, which is negative for all three policies. Row nine reports the change actually

[40] This is the lower bound estimate. The upper bound estimate is \$256.89.

Table 7
Aggregate summary of all policies

| | Land protection policy I | Land protection policy II | Growth ring policy |
|---|---|---|---|
| Acres protected | 9859 | 4176 | . |
| Number of parcels protected | 27 | 82 | . |
| Average parcel size (acres) | 365.15 | 50.93 | . |
| Change in avg. zone augmentation parameter | +0.0041 | +0.0145 | . |
| Change in residential acres | −298.462 | −506.631 | −2667.71 |
| Change in developed acres/acres protected | 0.03 | 0.121 | . |
| Percent change in average lot size | −0.459% | −0.836% | −4.171% |
| Change in average zone public good level | −0.00037 | −0.00096 | −0.0039 |
| Change in avg. household's public good level | +0.00049 | +0.0039 | +0.00104 |
| Percent change in avg. zone land price | −0.230% | −0.292% | +5.74% |
| Average capitalization change (lo) | −$7.86 | −$2.50 | −$0.16 |
| Average capitalization change (hi) | −$7.78 | −$0.84 | +$117.30 |
| Average CV for policy | $5.69 | $26.59 | −$150.07 |
| Avg. CV + Average capitalization change (lo) | −$2.17 | +$24.09 | −$150.23 |
| Avg. CV + Average capitalization change (hi) | −$2.09 | +$25.75 | −$32.77 |
| Average partial CV (no adjustments) | +$2.61 | +$47.35 | . |
| Average partial CV (no public good adjustment) | −$4.32 | +$18.62 | −$171.36 |

experienced by households which is positive under all three policies—reflecting that on average, in equilibrium, households relocate to zones that are closer to the open space 'bliss point.'

Rows 11–15 of the table summarize the welfare calculations for the different policy scenarios. Rows eleven and twelve report the low and high estimates of capitalization changes.[41] The capitalization changes are tightly bounded for the land protection policies. This is not the case for the development freeze policy. The large difference stems from the problem that no lower bound (above $0.00) on the reservation price is available for those parcels that were developed under the baseline scenario, but are blocked from development by the proposed policy. For the development freeze policy, under which development is blocked in large sections of the county, the lower bound reservation price of $0.00 leads to an extreme lower bound. The upper bound, which assumes a reservation price equal to the baseline residential price, is likely to more closely reflect the true measure. These results demonstrate that there is heterogeneity in the effects of the different policies on land capitalization. The Growth Ring Policy leads to positive capitalization effects and Land Protection Policies I and II lead to negative capitalization.

Row thirteen reports the average Compensating Variation (CV) for each of the policies and rows fourteen and fifteen report the sum of average land appreciation and average CV for the policies. In general these two components of the total welfare effect appear to be of equal importance for calculating the total welfare impacts of the policies. They capture the difference in welfare between owners and renters. The total welfare calculations reveal that even though the Growth Ring policy is the most effective in increasing urban density, this change comes with a marked reduction in average household welfare particularly for households that rent and do not own their homes.

[41] For each household, these are calculated as discussed above in footnote 36.

The final two rows of Table 7 evaluate the importance of general equilibrium adjustments and endogenous public goods adjustments in determining the average CV for the policies. The first of these two rows reports the CV for additional open space protection (Land Protection Policies) under the assumption of no adjustments—households remain in their initial locations, prices are fixed, and endogenous public goods levels do not adjust. This measure is similar to what would be produced based on the use of marginal willingness to pay estimates derived from an hedonic regression. These estimates vary markedly from the total willingness to pay figures reported in row 13, even differing in sign for one of the land protection policies. The final row of the table explores the relative importance of the endogenous change in public good levels for explaining the difference between the partial and general equilibrium CV estimates. It adjusts the general equilibrium CV measure by subtracting the average change in experienced public good level from each household's experienced public good level under the new equilibrium (holding all other endogenous variables fixed at the new equilibrium levels) and then calculating the CV. The difference between these results and the general equilibrium CV estimates yield a rough estimate of the importance of the endogenous public good adjustments for the overall welfare impact of the policies. The results suggest that the endogenous public goods adjustments play an important role in the overall welfare measurements.

## 8. Conclusions

Open space protection and "anti-sprawl" policies are proliferating in the US. This paper advances the work on empirical locational equilibrium models to provide an initial analysis of these policies in a framework that incorporates the endogeneity of both privately held open space and land conversion decisions. The results highlight the importance of these adjustments for understanding the impacts of land market interventions.

From a policy perspective, four key results emerge. First, increasing the quantity of protected open space may not reverse a trend toward low density development. Accounting for changes in privately held open space reveals that increasing the quantity of land in public preserves may actually lead to a decrease in the total quantity of open space in a metropolitan area. Second, location matters. Different strategies for spending the same amount of money to purchase open space lead to markedly different outcomes from both a density and welfare perspective. Third, traditional valuation methods are inadequate for evaluating different policies because partial equilibrium welfare calculations are extremely poor predictors of their general equilibrium counterparts. And finally, while the analysis suggests that currently popular growth ring or urban growth boundary strategies can be effective in reducing the total developed acreage in metropolitan areas, this reduction in developed acreage is, however, associated with a large net welfare loss—particularly for households that rent their homes.

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