DISCUSSION PAPERS IN ECONOMICS

Working Paper No. 04-03

Endogenous Open Space Amenities in a Locational Equilibrium

Randall P. Walsh
Department of Economics, University of Colorado at Boulder
Boulder, Colorado

February 2004

Center for Economic Analysis
Department of Economics

University of Colorado at Boulder
Boulder, Colorado 80309

Endogenous Open Space Amenities in a Locational Equilibrium

Randall P. Walsh[1]
University of Colorado

Comments Welcome.
February, 2004

---

[1] The author thanks Helen Ladd, Tom Nechyba, Holger Sieg, and especially V. Kerry Smith for their help and support. The author also thanks H. Spencer Banzhaf, Mark Coppejans and Roger Von Hafen for their help and comments. Dissertation support from Resources For the Future and the Lincoln Institute of Land Policy is gratefully acknowledged. The views presented in the paper are those of the author and not the supporting institutions.

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 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.

In addition to its policy relevance, The paper makes two methodological contributions to the locational equilibrium literature. 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, Romer, and Sieg (2001) 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. These methodological contributions are central to the resulting policy analysis.

1 Introduction

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 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.

In addition to its policy relevance, The paper makes two methodological contributions to the locational equilibrium literature. 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. (2001) 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. These methodological contributions are central to the resulting policy analysis.

The analysis focusses on Wake County, North Carolina the site of the state capitol and one of the fastest growing metropolitan areas in the United States.[1] Four aspects of

---

[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 3,500 per year to 8,000 per year over the last 10 years.

land protection policies and growth restrictions influence their impacts. 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 the role of differences in the suitability of different locations for development. Finally, households' 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.

This paper develops a general equilibrium (GE) residential land market model. Household preferences are estimated using an extension of the empirical locational equilibrium model initially proposed by Epple and Sieg (1999). Differentiation in the suitability for development is incorporated using a spatially explicit land supply model developed in Walsh (2004). These two components are combined to generate the land market equilibrium model.[2] Combining these two empirical components into a single computational model makes it possible to evaluate spatially delineated open space policies.

The remainder of the paper is organized into six sections. section two develops a theoretical model of land market equilibrium with endogenous landscape amenities. Section three presents the implementation strategy for the locational equilibrium model. Section four describes the data used in the analysis. Section five presents estimation results. Section six develops the policy simulations and presents general equilibrium computations for the policy experiments. Finally, section seven summarizes the conclusions.

---

[2] Sieg, Smith, Banzhaf, and Walsh (2003) adapt the Epple-Sieg (1999) model to a G.E. framework based on constant elasticity housing supply functions. This work extends their methodology by endogenizing the location specific amenities (open space), allowing for more complex substitution patterns between public goods by introducing augmented prices, and developing a more detailed description of the supply side of the model.

2 The Link Between Household Choices and Open Space

This section considers a selection of the empirical literature on open space amenities and outlines a formal model for household preferences to reflect some of the features identified in that literature.

2.1 Background

Most studies dealing with open space amenities use hedonic housing price models[3] and can not be used to evaluate non-marginal policies.[4] Weicher and Zerbst (1973) present one of the earliest examples, considering amenities from neighborhood parks in Columbus, Ohio that are assumed to be captured by a set of dummy variables describing immediate adjacency to protected open space. They find positive price effects only for houses which directly face protected open space. For Boulder Colorado, Correll, Lillydahl, and Singell (1978) 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. They find that distance to open space as an indicator of a reduction in the 'quasi-public' aspect of open space leads to a $4.20 reduction in expected housing price. Recent analysis by Geoghegan,

---

[3] Contingent valuation methods have also been used to study consumer preferences over open space amenities. For example Halstead (1984) provides estimates of Massachusets' resident WTP for protecting agricultural land and Ready, Berger, and Blomquist (1997) provide measures of the willingness to pay of Kentucky residents for a program that would provide incentives for horse breeders to locate in the state. These studies recover consumers' willingness to pay for a movement from one state of the world to another. Successful policy analysis therefore requires a complete understanding of the price and amenity levels that will be available after the policy is implemented. Thus, the methodology is of limited use in this application.

[4] There are three qualifications to this point. First, Palmquist (1992) demonstrates that in the case of localized externalities (for example highway noise in a single neighborhood), reduced form hedonic models are sufficient for welfare measurement of non-marginal changes. Second, Bartik (1988) provides a methodology for identifying bounds on the WTP of non-marginal changes based on hedonic models. Finally, in recent work, Ekeland, Heckman, and Nesheim (2002) demonstrate that in general, even in a single market, the hedonic model is non-parametrically identified. They propose an approach which makes it possible to recover technology and preferences in a separable version of the hedonic model. They further argue that identification strategies incorporating cross-market data are based on economically implausible assumptions about why hedonic functions vary across markets.

Wainger, and Bockstael (1997) confirms these effects for landscape amenities.[5]

2.2 Modelling 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 consider two distinct types of open space amenities. The decision to develop individual lots, based on prices and lot characteristics, are aggregated to yield neighborhood specific residential land supply functions.

2.2.1 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.[6] 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.[7]

---

[5] The studies cited here only scratch the surface in terms of the valuation of open space. See for instance Lee and Linneman (1998), Li and Brown (1980) and Greenwood and Hunt (1989) on the valuation of public parks; Halstead (1984), Ready et al. (1997) , Kline and Wichelns (1994), Bergstrom, Dillman, and Stoll (1985), Bolitzer and Netusil (2000) and Mahan, Polasky, and Adams (2000) on privately owned open space; Acharya and Bennett (2001) on the value of land cover surrounding housing; and Tyrvainen and Miettinen (2000), Rodriguez and Sirmans (1994), and Benson, Hansen, Schwartz, and Smersh (1998) on the value of natural views.

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

[7] For tractability, the levels of non-residential development are treated as exogenous and are not formally modelled.

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 α_i. Implementation of the model is facilitated by adopting the indirect preference specification given in equation 2.1.

$$V(P_j, O_j^p, O_j^n, A_j | y_i, \alpha_i) = \left[\frac{1}{1-\nu}\ y_i^{1-\nu} - \frac{1}{1+\eta} B \left(\frac{P_j}{1+(O_j^p)^\lambda} \right)^{\eta+1} \right] G(O_j^n, A_j)^{\alpha_i} \quad (2.1)$$

Under this specification, the private services provided by differential access to protected open space are treated as a quality adjustment to lot price where the quality adjusted price $\widetilde{P}_j$ is defined as in equation 2.2.

$$\widetilde{P}_j(P_j, O_j^p) \ = \ \frac{P_j}{1+(O_j^p)^\lambda} \quad (2.2)$$

This approach is consistent with Willig's (1978) pure re-packaging model using a functional form suggested by Hanemann (1984).[8] The price elasticity of land is generally less than one. As a result, if the estimated value of λ is positive, O^p will have a substitutes relationship with residential lot size. G is an index of public services that includes the neighborhood open space measure, O^n and controls for additional neighborhood specific amenities A_j. α_i is assumed to capture the unobserved heterogeneity in household tastes for the index of locational attributes.[9]

---

[8] Hanemann's (1984) equation 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 $1 + (O_j^p)^\lambda$.

[9] 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 (1999). The slope of indifference curves in the $\{G, \widetilde{P}\}$ plane are given by:

$$M(\alpha, y, B, G, \widetilde{P}) \ = \ \left.\frac{d\widetilde{P}}{dG}\right|_{V=\bar{V}} \ = \ \frac{\alpha \left(\frac{1}{1-\nu}\ y^{1-\nu} \ - \ \frac{1}{1+\eta}\ B\ \widetilde{P}^{\eta+1} \right)}{G\ B\ \widetilde{P}^{\nu}} \quad (2.3)$$

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

The price of land, P_j, is assumed to equal the average 1992 land assessment per square foot annualized following Poterba's (1992) approach for incorporating tax and appreciation effects. The model assumes that 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 α_i respectively. The distribution parameters for these variables are not directly observed and are assumed to follow a bivariate log-normal distribution.

2.2.2 Supply Model

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 (2004)). Based on these estimates, the land supply function maps neighborhood specific residential land prices P_j to the supply of residential land in each neighborhood S_j as in equation 2.4.

$$S_j(P_j) = \overline{L}_j + \sum_{k \in j} F_{kj}\left[P_j\right] \; * \; \text{AREA}_{kj} \tag{2.4}$$

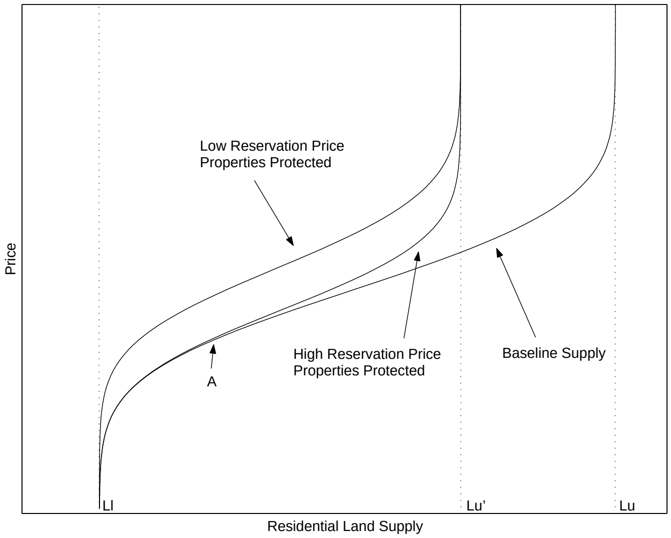
$F_{kj}[.]$ is the CDF for the reservation price of parcel k in zone j, AREA_{kj} is the area of parcel k and $\overline{L}_j$ is the area of land in residential use in neighborhood j as of 1984.[10] Figure 1 presents a graphical representation of equation 2.4 under the assumption of a logistic distribution of reservation prices.

Figure 1 also illustrates how government purchases of land affect the market. New land protection has two effects on supply in each zone. First, protection reduces the aggregate

---

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

Figure 1: Impact of Land Protection on Residential Land Supply Model



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

2.2.3 Equilibrium in the Land Markets

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, $O_j^n\left(\{j_i^*, d_i^*\}_{i \in I}\right)$. 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 equations 2.5 thru 2.8.

$$\forall\ i \quad j_i^* \ = \ \arg\max_{j \in J} \ \left\{ \ v\left[P_j, O_j^p, O_j^n, A_j |\ y_i,\ \alpha_i\right] \ \right\} \tag{2.5}$$

$$\forall\ i \quad d_i^* \ = \ - \ \frac{\frac{\partial\ v\left[P_j, O_j^p, O_j^n, A_j |\ y_i,\ \alpha_i\right]}{\partial P_{j_i^*}}}{\frac{\partial\ v\left[P_j, O_j^p, O_j^n, A_j |\ y_i,\ \alpha_i\right]}{\partial y_i}} \tag{2.6}$$

$$\forall\ j \quad S_j(P_j) \ = \ \sum_{i \in I} 1_{j_i^* = j} \cdot \ d_i(.) \tag{2.7}$$

$$\forall\ j \quad O_j^n \ = \ O_j^n\left(\{j_i^*, d_i^*\}_{i \in I}\right) \tag{2.8}$$

Equations 2.5 and 2.6 require each household to behave optimally at both the extensive and intensive margin. Equation 2.7 requires the residential land supply in zone j equals demand in zone j and 2.8 guarantees that the endogenous public good levels realized in each zone are obtained from the aggregation of each household's optimal choice as described in 2.5 and 2.6.

3 Estimation of Household Preferences

This 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.[11] 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. As a result it influences demand for lot size indirectly. This specification allows for heterogeneous tastes for the index of public goods (G) via the taste parameter α_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 parameter of the function mapping open space to the augmentation parameter (λ); and, the parameters of the public good index.

The parameters of the household utility model are estimated by taking advantage of the conditions for a locational equilibrium.[12] Following Epple and Sieg (1999) 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 parameters of the

---

[11] The approach taken here is related to two additional empirical approaches to estimating household sorting models that have been developed recently. Bayer (2000) extends the differentiated product model of Berry, Levinsohn, and Pakes (1995) 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, McMillan, and Rueben (2002) 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 (2000) and has been developed by Ferreyra (2001). 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 househeholds 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. (2002) and Ferreyra (2001). 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.

[12] As with all of the recent advances in estimating locational equilibrium models, this methodology requires the assumption of costless mobility.

augmentation function. The algorithm for the first stage begins with starting values for these first stage parameters. A simulation algorithm maps these parameter values into a unique vector (normalized to a relative scale) of local amenity levels (G-index) which implies a sorting across zones that matches the predicted zone populations to actual zone populations. Each iteration of the first stage parameter vector together with the implied relative levels of the public good indices leads to a unique sorting of households (characterized by income and taste for locational amenity levels) across zones. This sorting is used to recover a predicted distribution of land demands for each zone. Quartiles of the predicted land demand distribution for each zone are differenced from those actually observed in each zone. These differences form the basis of a Minimum Distance Estimator (MDE). A numerical optimization routine is then employed to find the set of parameters which minimize the value of the MDE's objective function. The specifics of estimation are presented in the Appendix.

4 Data

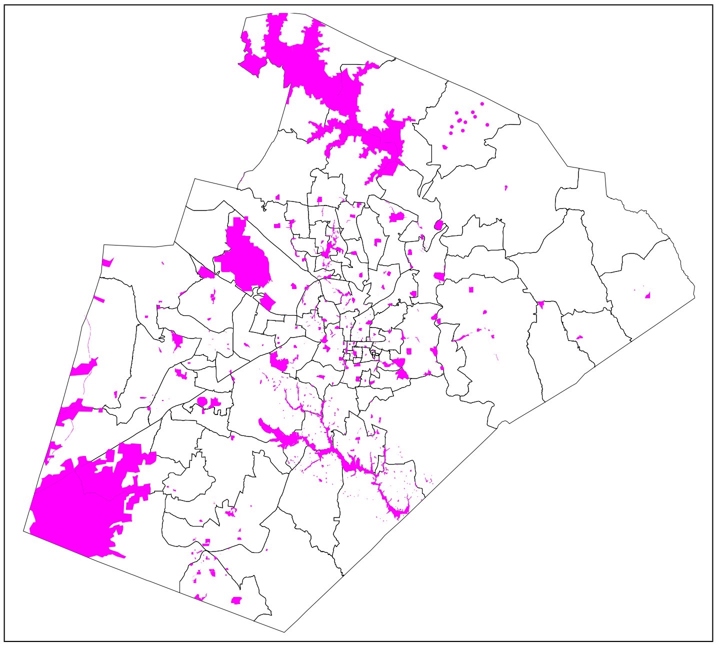
The study area for this project is Wake County, North Carolina. The county includes the state capital and a portion of the Research Triangle Park. It has experienced rapid development and contains significant areas of protected and unprotected open space. The empirical model requires dividing the county 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[13], that are as homogeneous as possible in location specific attributes. These 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

---

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

local jurisdictional boundaries, major roadways and school attendance boundaries. Figure 2 shows the boundaries of the 91 zones.

Figure 2: Map of 91 Zones and Protected Open Space



Shaded areas represent parcels of protected open space.

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.[14]

---

[14] 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.

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%

Two open space measures are developed for use in the locational equilibrium model. The first is the endogenous or neighborhood component of open space, O_j^n which 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 is the exogenous component of open space, O_j^p. This measure 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 the Army Corps of Engineers, North Carolina Department of Environment and Natural Resources and local planning agencies. The shaded areas in Figure 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 averages 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 average distance has a measure close to 1.[15] This approach creates a measure that is increasing in the level of amenity conveyed.

Additional data were collected to control for other location specific amenities.[16] To

---

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

[16] 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

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
Private 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

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 (1992), annualized rents are given by equation 4.9.

$$R = [(1-\tau)(i+\tau_p)+\beta+m+\delta-\pi]\ P_H \tag{4.9}$$

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

---

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.

Table 3: Values for Poterba Calculation

τ	owner's marginal tax rate	15%
τ_p	property tax rate (varies)	0.66% - 1.30%
i	interest rate	8.692%
β	risk premium	4%
m	maintenance	2%
π	home appreciation rate	2.886

5 Estimation Results

The estimated first stage parameters for the household location model are reported in table 4. Where it is possible to make comparisons with the existing literature they fall within the range of past estimates. Because within the framework of the model the variance of income is identified from the distribution in housing expenditures in the model, 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.[17] The estimated price elasticity of -.62 is consistent with Sirmans and Redman (1979) who compare price elasticities for 52 different urban areas for the years 1967, 1971 and 1975.[18] While significantly different from 0, the estimate of the correlation parameter ρ suggests little correlation between tastes for location specific amenities and permanent income.[19]

Finally, the estimated value of 21.83 for the augmentation parameter λ is consistent with the *a priori* expectation that private lot consumption and proximity to protected

---

[17] For example, Epple-Sieg (99) estimate .755 as the variance of ln current income in the Boston Metro area.

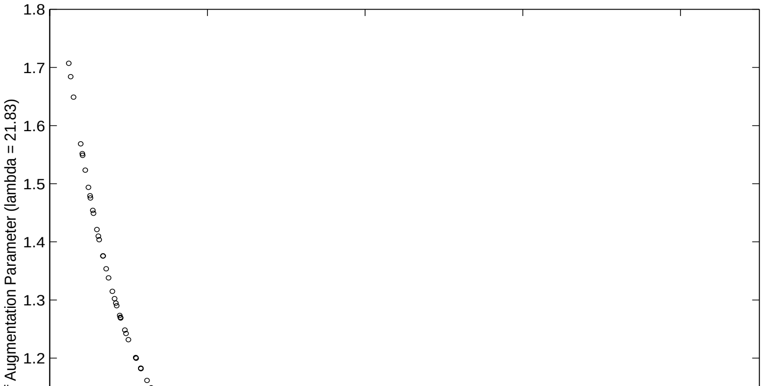
[18] While the literature has not identified income elasticities of demand for residential land, Polinsky (1977) provides estimates of housing demand income elasticities of .75.

[19] 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.

Table 4: Household Location Model's First Stage Parameter Estimates

	Parameter Estimate	Estimated Asymptotic S.E.
Variance of Ln (α)	0.2981	(0.0033)
Variance of Ln (y)	0.2823	(0.0061)
Price Elasticity (η)	-0.6174	(0.0166)
Income Elasticity (ν)	0.7474	(0.0844)
Demand Parameter (B)	1.5545	(0.0051)
α-y Correlation (ρ)	-0.0196	(0.004)
Augmentation Parameter (λ)	21.8257	(0.0001)

Figure 3: Effective Price Function - Household Location Model*



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

open space are substitutes. Figure 3 illustrates what the relationship implies for 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 $4,104. This estimate is less than that of Correll et al. (1978). Using their marginal willingness to pay measure of $4.20 per foot of walking distance 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.[20]

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, $\ln G_j = X_j'\gamma + \varepsilon_j$.

As is discussed in the appendix, two normalizations are required to identify the model's second stage. First, the model for $\widetilde{G}_j$ 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 γ, $\ln G_1$ and $\exp(\mu_{\ln\alpha})$. The moments used in estimation are then of the form in equation 5.10.

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)\,X_j' \tag{5.10}$$

.

---

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

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		X	0.3277
	(1.0205)	(0.5698)	(0.0082)	(1.0058)	(0.1021)			
V	-1.5687	0.2447	-0.0001	-0.4242	0.0792	X	X	0.3187
	(0.9456)	(0.4785)	(0.0069)	(0.9500)	(0.1089)			

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 the error term ε. However, equation 5.10 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 ε. The Instrumental Variables Estimator is defined by equation 5.11.

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)\,Z_j' \tag{5.11}$$

The results for five second stage specifications are presented in Table 5. Models I thru 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). 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 α which is labelled 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.[21] 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 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 through V incorporate the mean distance to eight different employment centers as explanatory variables.[22] All three 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.[23] 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

---

[21] 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.

[22] See Walsh (2002) 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.

[23] Instruments include measures of agricultural productivity, suitability for development, septic system potential and the presence of soils associated with wetlands. See Walsh (2004) for details of the construction of these variables.

points in the range of 0.30 to 0.33. These empirical 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. 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.

6 Policy Simulations

This section of the paper utilizes the estimated household model to evaluate the impacts of different policy interventions. Three 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.

6.1 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 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.

Land is assumed to be protected by both fee simple transfers and the purchase of development rights (PDR).[24] Derr and Dhillon (1999) suggest that 2/3 to 3/4 of market

---

[24] An overview of easement valuation issues is contained in Wiebe and Tegene (1996). For specific discussion

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 Figure 4.

The first four rows of Table 7 summarize the implementation of the policies. The land protection 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.

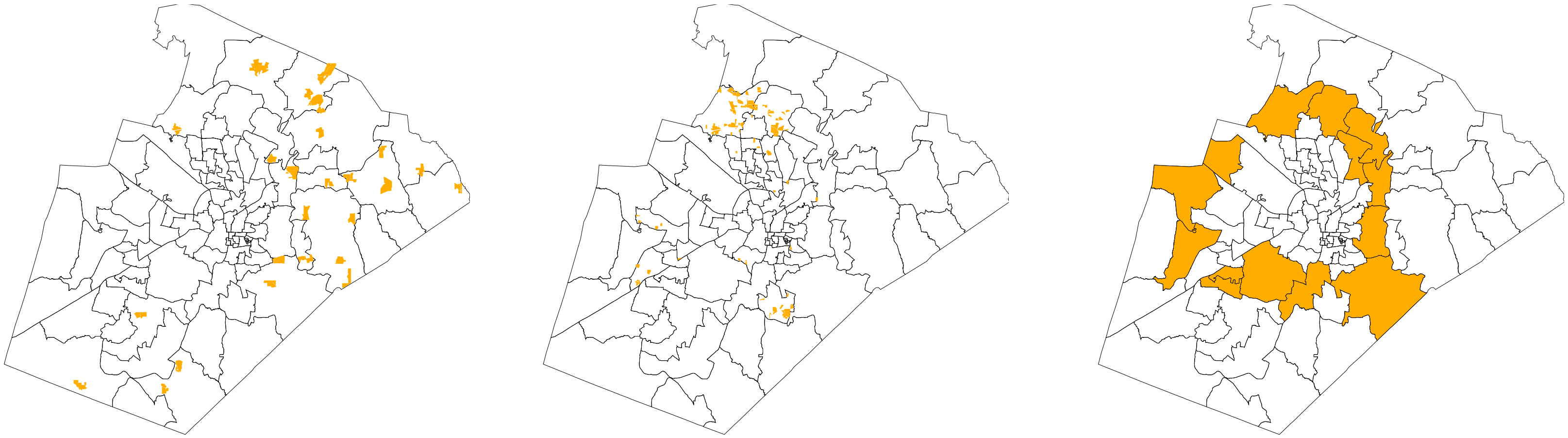
Policy I identifies the largest parcels in forested or agricultural use for protection first. These parcels are sorted from those containing the highest total acreage to those containing the lowest total acreage. Land protection starts with the largest in this ordering and continues through the list until \$25 million worth of property is identified.[25] Twenty seven parcels with an average size of 365 acres are protected across 16 zones. A total of 9,859 acres are protected at prices ranging from \$681 per acre to \$5,165 per acre. The average land price under this policy is \$2,208 per acre. Policy II targets protection activities to the most 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 4,176 acres. The average land price for protected parcels is \$5,340 per acre. The minimum price under this policy is \$4,321 per acre and the maximum is \$11,913 per acre. The final policy replicates a growth ring or urban growth boundary. It identifies a set of zones in Wake County and freezes residential development in these

---

of the issues associated with the value of the option to develop see Tegene, Wiebe, and Kuhn (1999).

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

Figure 4: Policy Simulations



Land Protection Policy I

Land Protection Policy II

Growth Ring Policy

Shaded areas represent the additional protected land under each policy.

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

zones at their 1984 levels by fixing the model's land supply function for these zones at their 1984 level of residential development. 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 zones chosen for inclusion in this policy (identified in Figure 4) are those closest to the center of the county with a 1984 density of development less than .1 residential households per acre.

Implementation of the final policy differs from that of the land protection policies. First, no new protected open space is created under the growth ring policy so no adjustments are made to the open space access measure, O^p, for the different zones. Second, the land supply adjustments for the policy are an order of magnitude greater than those for the land protection policies.

6.2 Computing the Land Market Equilibrium

The Land Market Equilibrium Model combines 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 (2004). This paper provides estimates of 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 (2001). In addition to price, the determinants of conversion include productivity in agricultural use, physical characteristics 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. The vector of zone specific endogenous land amenities (open space percentages) is fixed at an initial level and a vector of prices is identified which clears the land markets.[26] 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 deterimined 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.

6.3 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 Nash 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

---

[26] 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 (2002).

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.

6.4 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 new 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, 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 $(P^{'}_{j0} - P^{0}_{j0})$*Lot Size$^0_i$.[27]

To consider the respective impacts of these effects on the measured general equilibrium

---

[27] 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.

benefit, it is helpful to decompose the G.E. benefit measure as in equation 6.12

$$\begin{aligned}\text{Benefit}_i &= \left[y_i - e_i\left(\widetilde{P}(O^{p'}_{j0}, P^0_{j0}), G^0_{j0}, U^0_i\right)\right] \\ &+ \left[e_i\left(\widetilde{P}(O^{p'}_{j0}, P^0_{j0}), G^0_{j0}, U^0_i\right) - e_i\left(\widetilde{P}(O^{p'}_{j'}, P'_{j'}), G'_{j'}, U^0_i\right)\right] \; . \\ &+ \text{ Change in Capitalization}_i\end{aligned} \tag{6.12}$$

The first term in equation 6.12 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. This component of the benefit measure is labelled "Partial CV (No Adjustment)" in table 7.[28] The second term in equation 6.12 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.[29]

---

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

[29] In defining the change in capitalization to equal $(P'_j - P^0_j)$*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 $(P'_j * -r_i)$*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 $(r_i - P^0_j)$*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 policies, development is "reversed"

6.5 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.[30] 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[31] 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

---

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 these two policy simulations, the upper bound is likely to be closer to the actual capitalization change than is the lower bound.

[30] 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.

[31] 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 developed between 1984 and 1992.

(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.

The mechanics of the model under the Development Freeze Policy (Growth Ring) are identical to those of the Land Protection Policies, with two key distinctions. Under the development freeze, there is a more significant land supply effect in the impacted zones, but no additional public access open space is provided. As a result, O^P is assumed to remain unchanged in all zones. Direct impacts are therefore limited to those associated with the change in the land supply function in zones experiencing a development freeze.

To further appreciate how the components of the equilibrium lead to different aggregate outcomes, consider the outcomes in two different sets of zones under Land Protection Policies I and II. Zone 'Aj' is an example of a zone within which additional land is protected under land protection policy j and zone 'Bj' is an example of a zone which does not experience any additional open space protection under policy j.

Outcomes for four policy/zone pairs are presented in Table 6. The top portion of the table reports changes associated with 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. The first five rows of the table report data associated with the attributes of the partial equilibrium analysis. Rows six thru nine report equilibrium outcomes associated with each of the four policy/zone pairs. The bottom portion of the table reports the equilibrium outcomes for households that were initially located in each

Table 6: Decomposing the Policy Impacts

Policy Evaluated	**Policy I**		**Policy II**	
Sample Zone	**A1**	**B1**	**A2**	**B2**
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
G.E. 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	$240.76
Effects Experienced by Initial Residents of Sample Zone:				
Avg. Change in G-index	-0.004	-0.0001	-0.02867	-0.00257
Avg. Chng. in Aug. Price ($/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

of the four zones. The final row of Table 6 adds the property value change per household in the originating zone to the average G.E. WTP of households originating in that zone to yield a per household benefit measure.[32]

Under Policy I, in sample zone 'A1' the protection of additional open space in and around the zone leads to a 6.1% increase in the price 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

---

[32] These totals can be interpreted two ways: 1) This total represents the sum of renter CV for the policy plus the profit/loss of risk neutral landlords; or 2) Assuming that all households own their initial lot, this is a measure of the average total CV that ignores income effects associated with land appreciation/depreciation.

($66.37 per household). The general equilibrium calculation identifies additional changes. First, new location and lot size changes offset the newly protected open space yielding virtually no change in the percent of open space in the zone. Therefore there is 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.[33] 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 migration, zone A's households on average experience a decrease in 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 value yields a benefit estimate for zone 'A1' under policy I of $71.22 per household per year.

Because under policy I no new open space is protected in or near Zone 'B1', 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 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 locate in zones which provide small decreases in the G-index and small increases in augmented price.

---

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

These changes yield an average G.E. WTP measure for the zone's households of -\$15.39. In contrast to zone/policy pair '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 a positive capitalization change of \$240.76 per household.[34] This large change dominates the G.E. WTP for the zone's households, resulting in an annual benefit per household of \$172.32.

These results highlight three characteristics of the policy computations. First, partial equilibrium analysis yields distinctly different results from the general equilibrium analysis. Second, under both policies there is significant heterogeneity in outcomes across zones. Third, even in zones which experience no change in protected open space, direct and pecuniary spill-overs can lead to significant impacts.

6.6 Aggregate Policy Outcomes

Table 7 presents summary statistics for the changes, developed as policy specific aggregates, relative to the base-line model for the three different policy scenarios. The results

---

[34] 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 Average 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 Average Household's Public Good Level	+0.00049	+0.0039	+0.00104
Percent Change in Average 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

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. Because the household preference model incorporates access to open space through the price augmentation function, the change in the price augmentation factor measures how much the new land protection increased access to protected open space. Row four reports the average change in the price augmentation factor under the two land protection policies.[35] 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 table's fifth 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 .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.

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 2,668 acres. Row six reports the relationship between the number of acres protected and the reduction in development for the two Land Protection Policies. Row seven reports the change in average lot size and provides another measure of the overall impact on developed land. The growth ring policy has the largest

---

[35] Recall that the development freeze policy leaves this factor unchanged.

impact, reducing average lot size by 4.2%.

Row eight of the table reports the average (across zones) change in endogenous public good level. For some summary statistics such as this change in public good level, it unclear what is the appropriate unit of observation over which to calculate averages. Averaging across zones holds the zone constant, but due to 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 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'. Row ten reports the average change in zone land prices. Rows eleven and twelve report the low and high estimates of capitalization changes.[36] These figures reflect a combination of general equilibrium effects and the capitalization of changes in relative public good levels into residential land prices.

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". Therefore, the upper bound is likely to be the more closely reflect the actual measure. Without data on 1984 prices, it is impossible to provide definitive evidence of this relationship.

The results demonstrate that there is heterogeneity in the effects of the different policies

---

[36] For each household, these are calculated as discussed above in footnote 29.

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 bounds for 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.

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.

7 Conclusions

Open space protection and "anti-sprawl" policies are proliferating in the U.S. This analysis 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 associated with a large net welfare loss - particularly for households that rent their homes.

In addition to its policy relevance, The paper makes two methodological contributions to the locational equilibrium literature. 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. (2001) 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. These methodological contributions are central to the resulting policy analysis.

APPENDIX: Estimation of Locational Equilibrium Model

A two-stage process is used to estimate the parameters of the household model. The first stage isolates the heterogeneity parameters, indirect utility parameters, and the parameter of the augmentation function. These are labelled the first stage parameters. The basic algorithm for the first stage begins with an initial guess for the values of these parameters. A simulation algorithm maps these parameter values into a unique vector (normalized to a relative scale) of local amenity levels, the vector G, which implies a sorting across zones that matches the predicted zone populations to actual zone populations. Each iteration of the first stage parameter vector together with the implied relative levels of the public good indices leads to a unique sorting of households (characterized by income and taste for locational amenity levels) across zones. This sorting is used to recover a predicted distribution of land demands for each zone. Quartiles of the predicted distribution of lot sizes for each zone are differenced from those actually observed in each zone. These differences form the basis of a Minimum Distance Estimator (MDE). A numerical optimization routine is then employed to find the set of parameters which minimize the value of the MDE's objective function. Finally, the impact of different location amenities are on the levels of G are identified using a moment-based estimator to decompose the vector into a systematic component and idiosyncratic shocks.

The specifics of the model are as follows. Each household can choose to live in one of ninety-one discrete zones within a predefined metropolitan area. Conditional on choosing zone j, household i's indirect utility function is given by equation 2.1. P_j is assumed to equal the average 1992 land assessment per square foot annualized using Poterba's (1992) approach for incorporating tax and appreciation effects. Permanent income and heterogeneity in the taste for the locational attributes are introduced thru y_i and α_i respectively. These variables are not directly observed but are assumed to follow a bivariate log-normal distribution.

Using Roy's identity, conditional on choosing community j, household i's optimal residential land demand is given by:

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

η and ν are the price and income elasticity of demand for residential acreage respectively.

To illustrate how changes in G affect location decisions, consider the locus of households that are indifferent between community 1 and community 2, defined implicitly by the requirement:

$$\left[\frac{1}{1-\nu}\; y^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_1^{\eta+1}\right] G_1^{\alpha} \;=\; \left[\frac{1}{1-\nu}\; y^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_2^{\eta+1}\right] G_2^{\alpha} \tag{A.2}$$

This expression can be solved for α:

$$\alpha \;=\; \frac{\ln\left[\frac{\frac{1}{1-\nu}\; y^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_1^{\eta+1}}{\frac{1}{1-\nu}\; y^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_2^{\eta+1}}\right]}{\ln\left[\frac{G_2}{G_1}\right]} \tag{A.3}$$

Households whose endowments place them above the locus will choose to live in community 2 while those with endowments below the locus choose community 1. Equation A.3 establishes that as $\left[\frac{G_2}{G_1}\right]$ increases the indifference surface will shift down with those households located below, but near, the indifference locus defined by (A.2) moving from community 1 to community 2.

There is no closed form solution for the land demand quartiles that form the basis of the MDE estimator. As a result a simulation based estimator is used to identify the residual vector associated with each selection for the vector of preference parameters. The basic algorithm can be outlined as follows. Let X be a vector of $N = 250$ equally spaced numbers between 0 and 1.[37] Define $\hat{X} = F^{-1}(X)$, where $F^{-1}(.)$ is the inverse of the Normal CDF.

---

[37] Households are heterogeneous in 2 dimensions, income y and taste for the public good α. As is discussed

The vector $\hat{X}$ is used to generate a vector of N income draws consistent with the log normal distribution, given $\mu_{\ln y}$ and $\sigma_{\ln y}$.[38] For each potential vector of parameter values, define:

$$K_{12}^i = \ln\left[\frac{\frac{1}{1-\nu}\, y_i^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_1^{\eta+1}}{\frac{1}{1-\nu}\, y_i^{1-\nu} - \frac{1}{1+\eta} B\widetilde{P}_2^{\eta+1}}\right]. \tag{A.4}$$

The set of households preferring community 1 over community 2 (and hence the set of households who choose community 1) is given by:

$$C_{1\succ 2|y_i} \;=\; \left\{ \alpha \;\middle|\; \alpha \;<\; \frac{K_{12}^i}{\ln\left(\frac{G_2}{G_1}\right)} \right\} \tag{A.5}$$

Given G_1, we can solve for the measure of the population choosing community 1 as a function of G_2:

$$M_{1|G_1}(G_2) = \frac{1}{N}\sum_{i=1}^{N} F_{\alpha_i}\left[\frac{K_{12}^i}{\ln\left(\frac{G_2}{G_1}\right)}\right] \tag{A.6}$$

Where F_{α_i} is the Normal CDF with:

$$\text{Mean} \;=\; \mu_{\ln\alpha} + \frac{\sigma_{\ln\alpha}}{\sigma_{\ln y}}\,\rho\,(\ln y - \mu_{\ln y}) \tag{A.7}$$

$$\text{Variance} \;=\; \sigma_{\ln\alpha}^2\,(1-\rho^2). \tag{A.8}$$

At this stage of the analysis, it is not possible to identify the absolute levels of the G-index vector or the mean of the log of α. To illustrate this problem, re-write equation

---

below, conditional on income level it is possible to analytically integrate over the distribution of α. Previous work with this type of model has numerically integrated over both dimensions of the heterogeneity. The resolution achieved with the approach taken here will exceed that achieved when $250^2 = 62,500$ draws are used to integrate numerically in both dimensions.

[38] Specifically, $y_i = exp(\mu_{\ln y} + \hat{X}_i\, \sigma_{\ln y})$. The actual process is slightly more complicated. First, because the utility specification is inconsistent for extremely low values of permanent income it is necessary to truncate the left edge of the distribution. This is done at \$6800, the 1990 poverty threshold for a one person family under the age of 65. Second, the mean of the income distribution is not identified separate of the demand parameter B. Therefore, conditional on $\sigma_{\ln y}$, the parameter $\mu_{\ln y}$ is chosen to yield a mean income equal to the observed mean income for Wake County. Specifically, $\mu_{\ln y} = \ln(\overline{Y}) - \sigma_{\ln y}^2/2$. Where $\overline{Y}$ is the observed mean income for the County.

A.5 as follows.

$$C_{1 \succ 2|y_i} \;=\; \left\{ \alpha_i \;\middle|\; \ln\left(\frac{G_2^{\alpha_i}}{G_1^{\alpha_i}}\right) \;<\; K_{12}^i \right\} \tag{A.9}$$

This expression suggests that only relative levels of the G-index vector can be identified. Less obvious is the second identification problem involving the mean of the log of the taste heterogeneity parameter α_i. The problem is as follows.

Define:

$$\alpha_i \;=\; \exp(\widetilde{\alpha_i}) \tag{A.10}$$

By assumption:

$$(\ln y_i, \widetilde{\alpha_i}) \;\sim\; N(\mu, \Sigma) \tag{A.11}$$

Each household can be represented by functions of draws on the random variables $R_{\alpha i}, R_{yi}$, where $R_{\alpha i}, R_{yi}$ are defined by:

$$\begin{bmatrix} R_{\alpha i} \\ R_{yi} \end{bmatrix} \;=\; \Sigma^{\frac{1}{2}} Z_i \tag{A.12}$$

where Z_i is a random draw from the bivariate normal with mean 0, covariance 0 and variance 1 and Σ is the covariance matrix of $\ln y_i$ and $\ln \alpha_i$. Draws of $\widetilde{\alpha}_i$ can be constructed based on draws from $R_{\alpha i}$:

$$\widetilde{\alpha}_i \;=\; \mu_{\widetilde{\alpha}} \;+\; R_{\alpha i} \tag{A.13}$$

Substituting back into G^{α_i}:

$$G^{\alpha_i} \;=\; G^{\exp(\widetilde{\alpha}_i)} \;=\; G^{\exp(\mu_{\widetilde{\alpha}} \,+\, R_{\alpha i})} \;=\; G^{\exp(\mu_{\widetilde{\alpha}})\exp(R_{\alpha i})} \;=\; \left[G^{\exp(\mu_{\widetilde{\alpha}})}\right]^{\exp(R_{\alpha i})}$$

Substituting this result into the key expression from equation A.9 and generalizing to zone j yields equation A.14.

$$\frac{G_j^{\alpha_i}}{G_1^{\alpha_i}} \;=\; \left[\frac{G_j^{\exp(\mu_{\widetilde{\alpha}})}}{G_1^{\exp(\mu_{\widetilde{\alpha}})}}\right]^{R_{\alpha i}} \;=\; \widetilde{G}_j^{R_{\alpha i}} \tag{A.14}$$

In the first stage, the vector of $J-1$ values of $\widetilde{G}_j$ are identified. Equation A.14 indicates that the $J-1$ elements of the G vector are defined conditional on G_1 and $\mu_{\widetilde{\alpha}}$. Thus, for any arbitrary values of G_1 and $\mu_{\widetilde{\alpha}}$ there will exist a set of values for G_2 thru G_J which satisfy equation A.14. It is therefore necessary to choose a normalization for μ_{ln_α}.

In order to estimate the first stage parameters, including the vector of $\widetilde{G}_j$ values, G_1 is set equal to one and $\mu_{\ln\alpha}$ is set equal to zero.[39] The value of G_2 is then defined implicitly by equation A.6. This implied value of G_2 is identified using a line search algorithm. The solution algorithm iterates through the communities to solve for the entire G vector. Once this vector has been identified, the income quartiles in each zone can be identified. These income quartiles are then substituted into the land demand function implied by Roy's identity in equation A.1 to derive the land demand quartiles that form the basis of the MDE.

The specific form of the Minimum Distance Estimator (MDE) is given in equation A.15.

$$\hat{\theta} \;=\; \underset{\theta\in\Theta}{\operatorname{argmin}}\; M(\theta)'\;\mathbf{W}\;M(\theta) \tag{A.15}$$

---

[39] These normalizations only serve to identify the first stage parameters, which are invariant to this normalization, and are *not* utilized for identification of the second stage parameters.

where θ is the vector of first stage parameters. The vector $M(\theta)$ is constructed as follows:

$$M(\theta) \;=\; \left[\begin{array}{c} \sqrt{\frac{N_1}{N}}\begin{pmatrix} \widehat{Q_1}(\theta,.25) - Q_1(.25) \\ \widehat{Q_1}(\theta,.50) - Q_1(.50) \\ \widehat{Q_1}(\theta,.75) - Q_1(.75) \end{pmatrix} \\ \vdots \\ \sqrt{\frac{N_J}{N}}\begin{pmatrix} \widehat{Q_J}(\theta,.25) - Q_J(.25) \\ \widehat{Q_J}(\theta,.50) - Q_J(.50) \\ \widehat{Q_J}(\theta,.75) - Q_J(.75) \end{pmatrix} \end{array}\right]. \tag{A.16}$$

$\widehat{Q_j}(\theta,.25)$ is the predicted value of the 25th lot size quantile in zone j when the model's first stage is evaluated at the parameter value θ and $Q_j(.25)$ is the observed 25th quantile in zone j. N is the total number of observations used to construct the quantile measures and N_j is the number of observations in aone j.

At the true value of the parameter vector θ_0 the only source of variance in $M(\theta_0)$ is sampling error in the estimates of the observed quantiles of the lot size distribution in each community. Therefore the Central Limit Theorem implies the limiting distribution for $M(\theta)$ presented in equation A.17:

$$.\sqrt{N}\; M(\hat{\theta}) \;\overset{D}{\rightarrow}\; \mathrm{N}(0,\boldsymbol{\Sigma}) \tag{A.17}$$

where $\boldsymbol{\Sigma}$ is the block diagonal matrix:

$$\boldsymbol{\Sigma} \;=\; \begin{bmatrix} \boldsymbol{\Psi}_1 & & 0 \\ & \ddots & \\ 0 & & \boldsymbol{\Psi_J} \end{bmatrix} \tag{A.18}$$

and $\mathbf{\Psi}_j$ is given by:[40]

$$\mathbf{\Psi}_j \;=\; \begin{bmatrix} \frac{3}{16\ f_j^2\left(Q_j^{.25}\right)} & \frac{1}{8\ f_j\left(Q_j^{.25}\right)\ f_j\left(Q_j^{.5}\right)} & \frac{1}{16\ f_j\left(Q_j^{.25}\right)\ f_j\left(Q_j^{.75}\right)} \\ \frac{1}{8\ f_j\left(Q_j^{.25}\right)\ f_j\left(Q_j^{.5}\right)} & \frac{1}{4\ f_j^2\left(Q_j^{.5}\right)} & \frac{1}{8\ f_j\left(Q_j^{.5}\right)\ f_j\left(Q_j^{.75}\right)} \\ \frac{1}{16\ f_j\left(Q_j^{.25}\right)\ f_j\left(Q_j^{.75}\right)} & \frac{1}{8\ f_j\left(Q_j^{.5}\right)\ f_j\left(Q_j^{.75}\right)} & \frac{3}{16\ f_j^2\left(Q_j^{.75}\right)} \end{bmatrix}. \tag{A.19}$$

$f_j\left(Q_j^{.25}\right)$ is the pdf of the distribution of lot size in the jth community evaluated at the .25 quantile, and $f_j^2\left(Q_j^{.25}\right)$ is the square of the pdf of the distribution of lot size in the jth community evaluated at the .25 quantile.[41] The asymptotic theory for MDE's presented in Newey and McFadden (1994) can be used to develop asymptotic estimates of the asymptotic covariance matrix of $\hat{\theta}$. Setting $\mathbf{W} \;=\; \mathbf{\Sigma}^{-1}$ yields:

$$\hat{\theta} \;\overset{D}{\rightarrow}\; \mathrm{N}\left[\theta_0, \frac{1}{N}(\mathbf{G}'\ \mathbf{W}\ \mathbf{G})^{-1}\right] \tag{A.20}$$

Where $\mathbf{G}$ is the $3J \times k$ matrix given by:

$$\mathbf{G} \;=\; \frac{\partial\ M(\hat{\theta})}{\partial\ \theta}. \tag{A.21}$$

One final issue related to the estimation of the first stage parameters is the treatment of the income in the model. The scale parameter of the land demand, B, and the mean of permanent income are not separately identified, estimation of the preference parameters requires an estimate of the mean permanent income in Wake County. Therefore, to estimate B a separate measure of the mean of permanent income in Wake County is introduced using Woods-Poole (1995). BEA's Personal Income Series was used to develop the measure (\$56,123).

To decompose the G-index, in the second stage of the estimation procedure the locational attributes index is assumed to follow a semi-log function, $G_j = \exp(X_j'\gamma + \varepsilon_j)$. G_1 is treated

---

[40] See Mood, Graybill, and Boes (1974) For a discussion of the asymptotic variance of order statistics.

[41] These values are estimated non-parametrically using kernel estimators.

as a nuisance parameter to be estimated as part of the second stage of the model. This yields the following linear model:

$$\frac{\ln(\widetilde{G}_j)}{\exp(\mu_{\ln\alpha})} \;=\; -\ln G_1 + X_j'\gamma + \varepsilon_j \tag{A.22}$$

Two normalizations identify this model. First, the intercept of the semi-log model is assumed to equal $\ln G_1$. Second the coefficient on the first element of the local public good index is set equal to 1. Under this normalization, the coefficients on locational attributes can be interpreted relative to this first element and the value of $\mu_{\ln\alpha}$ reflects, on average, the relative importance of the locational attribute index in preferences.

A GMM procedure is then utilized to estimate the model's second stage parameters. The parameter vector is comprised of the parameters of the index γ,[42] $\ln G_1$ and $\exp(\mu_{\ln\alpha})$. The moments used in estimation are then of the form in equation A.23.

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)\,X_j' \tag{A.23}$$

where ε_j as derived from equation A.22 and is given in equation A.24.

$$\varepsilon_j = \frac{\ln(\widetilde{G}_j)}{\exp(\mu_{\ln\alpha})} + \ln G_1 - X_j'\gamma. \tag{A.24}$$

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 the error term ε. However, equation A.23 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 ε. The Instrumental Variables Estimator is defined by equation A.25.

$$\frac{1}{J}\sum_{j=1}^{J}(\varepsilon_j)\,Z_j'. \tag{A.25}$$

---

[42] Recall that the parameter on open space percentage is fixed at one.

References

Acharya, G. and Bennett, L. (2001). Valuing Open Space and Land-Use Patterns in Urban Watersheds. *Journal of Real Estate Finance and Economics*, *22*, 221–237.

Bartik, T. (1988). Measuring the Benefits of Amenity Improvements in Hedonic Price Models. *Land Economics*, *64*, 172–183.

Bayer, P. (2000). Exploring Differences in the Demand for School Quality: An Empirical Analysis of School Choice in California. Working Paper.

Bayer, P., McMillan, R., and Rueben, K. (2002). Exploring Differences in the Demand for School Quality: An Empirical Analysis of School Choice in California. Working Paper.

Benson, E., Hansen, J., Schwartz, A., and Smersh, G. (1998). Pricing Residential Amenities: The Value of a View. *Journal of Real Estate Finance and Economics*, *16*, 55–73.

Bergstrom, J., Dillman, B., and Stoll, J. (1985). Public Environmental Amenity Benefits of Private Land: The Case of Prime Agricultural Land. *Southern Journal of Agricultural Economics*, *17*(1), 139–49.

Berry, S., Levinsohn, J., and Pakes, A. (1995). Automobile Prices in Market Equilibrium. *Econometrica*, *63 (4)*, 841–890.

Bolitzer, B. and Netusil, N. (2000). The Impact of Open Spaces on Property Values in Portland, Oregon. *journal of environmental management*, *59*, 185–193.

Correll, M., Lillydahl, J., and Singell, L. (1978). The Effects of Greenbelts on Residential Property Values: Some Findings on the Political Economy of Open Space. *Land Economics*, *54*(2), 207–217.

Derr, D. and Dhillon, P. (1999). *Purchase of Development Rights Program, the Northeast Experience*, pp. 93–112. Ashgate Publishing.

Ekeland, I., Heckman, J., and Nesheim, L. (2002). Identifying Hedonic Models. *American Economic Review*, *92*(2), 304–309.

Epple, D., Romer, T., and Sieg, H. (2001). Interjurisdictional Sorting and Majority Rule: An Empirical Analysis. *Econometrica*, *69*(6), 1437–1465.

Epple, D. and Sieg, H. (1999). Estimating Equilibrium Models of Local Jurisdictions. *Journal of Political Economy*, *107(4)*, 645–681.

Ferreyra, M. (2001). Estimating the Effects of Private School Vouchers in Multi-District Economies. Working Paper.

Geoghegan, J., Wainger, L., and Bockstael, N. (1997). Spatial Landscape Indices in a Hedonic Framework: an Ecological Economics Analysis Using GIS. *Ecological Economics*, *23*, 251–264.

Greenwood, M. and Hunt, G. (1989). Jobs Versus Ameneties in the Analysis of Metropolitan Migration. *Journal of Urban Economics*, *15*, 1–16.

Halstead, J. (1984). Measuring the Non-Market Value of Massachussets Agricultural Land: a Case Study. *Journal of Northeastern Agricultrual Economic Council*, *13*(1), 226–247.

Hanemann, W. (1984). Discrete/Continuous Models of Consumer Demand. *Econometrica*, *52*, 541–561.

Kline, J. and Wichelns, D. (1994). Using Referendum Data to Characterize Public Support for Purchasing Development Rights to Farmland. *Land Economics*, *70*(2), 223–233.

Lee, C. and Linneman, P. (1998). Dynamics of the Greenbelt Amenity Effect on the Land Market-The Case of Seoul's Greenbelt. *Real Estate Economics*, *26*(1), 107–129.

Li, M. and Brown, H. (1980). Micro-Neighborhood Externalities and Hedonic Housing Prices. *Land Economics*, *56*(2), 125–141.

Mahan, B., Polasky, S., and Adams, R. (2000). Valuing Urban Wetlands: A Property Price Approach. *Land Economics*, *76*, 100–113.

Mood, A., Graybill, F., and Boes, D. (1974). *Introduction to the Theory of Statistics*. McGraw-Hill.

Nechyba, T. (2000). Mobility, Targeting and Private School Vouchers. *American Economic Review*, *90*, 130–146.

Nevo (2001). Measuring Market Power in the Ready-to-Eat Cereal Industry. *Economietrica*, *69*(2), 307–342.

Newey, W. and McFadden, D. (1994). Large Sample Estimation and Hypothesis Testing. In *Handbook of Econometrics IV*. Elsevier North Holland.

Palmquist, R. B. (1992). Valuing Localized Externalities. *Journal of Urban Economics*, *31*, 59–68.

Polinsky, A. (1977). The Demand for Housing: A Study in Specification and Grouping. *Econometrica*, *45*(2), 447–461.

Poterba, J. (1992). Taxation and Housing: Old Questions, New Answers. *American Economic Review*, *82 (2)*, 237–242.

Ready, R., Berger, M., and Blomquist, G. (1997). Measuring Amenity Benefits from Farmland: Hedonic Pricing vs. Contingent Valuation. *Growth and Change*, *28*, 438–458.

Rodriguez, M. and Sirmans, C. (1994). Quantifying the Value of a View in Single-Family Housing Markets. *Appraisal Journal*, *62*, 600–603.

Sieg, H., Smith, V., Banzhaf, H., and Walsh, R. (2003). Measuring the Impact of Air Quality on Housing Markets and Residential Choices in Southern California. Discussion Paper.

Sirmans, C. and Redman, A. (1979). Capital-Land Substiturion and the Price Elasticity of Demand for Urban Residential Land. *Land Economics*, *55*(2).

Tegene, A., Wiebe, K., and Kuhn, B. (1999). Irreversible Investment Under Uncertainty: Conservation Easements and the Option to Develop Agricultural Land. *Journal of Agricultural Economics*, *50*(2), 203–219.

Tyrvainen, L. and Miettinen, A. (2000). Property Prices and Urban Forest Amenities. *Journal of Environmental Economics and Management*, *39*(2), 205–223.

Walsh, R. (2002). *Analyzing Open Space Policies in a Computable Locational Equilibrium Model*. Dissertation, Duke University.

Walsh, R. (2004). An Empirical Model of Land Conversion. Discussion Paper.

Weicher, J. and Zerbst, R. (1973). Externalities of Neighborhood Parks: An Empirical Investigation. *Land Economics*, *49*(1), 99–105.

Wiebe, K. and Tegene, A. (1996). Partial Interests in Land: Policy Tools for Resource Use and Conservation. . USDA-Economic-Research-Service.

Willig, R. (1978). Incremental Consumer's Surplus and Hedonic Price Adjustment. *Journal of Economic Theory*, *17*, 227–253.

Woods-Poole (1995). *1996 State Profile: North Carolina*. Woods and Poole Economics, Inc., Washington, DC.