AMENITIES IN AN URBAN EQUILIBRIUM MODEL: RESIDENTIAL DEVELOPMENT IN PORTLAND, OREGON

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Abstract

This paper analyzes the effect of open space and other amenities on housing prices and development density within the framework of an urban equilibrium model. The model is estimated as a system of equations that includes households' residential choice decisions and developers' development decisions and emphasizes the importance of amenities in the formation of development patterns and property values. The model is applied to Portland, Oregon, where ambitious open space programs have been implemented. The results suggest that amenities are important: households are willing to pay more for newer houses located in areas of less dense development, with more open space, better views, less traffic congestion, and near amenity locations. For the developer, increases in housing prices result in an attempt to provide more and larger houses. The attempt to provide more houses, however, results in higher density, which will ultimately reduce prices. A simulation analysis evaluates the policy implications of the model results and indicates substantial benefits from alterations in housing patterns (JEL R11, R21, R31).

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I. Introduction

Since the 1970's, the land area occupied by urban and metropolitan areas in the United States has more than doubled, and the expansion has accelerated in recent years (U.S. Department of Agriculture).[1] The conversion of farmland and forests to such development has generated strong public support for growth management across the U.S.[2] For example, during 1998-2000, there were 454 "open space" measures placed on ballots in the U.S. Eight-four percent of these measures were approved, providing $17.1 billion for open space preservation (Land Trust Alliance, 2001). The appeal of open space preservation arises from the associated recreational opportunities, visual amenities, and other environmental and ecosystem benefits. Conversely, conversions of open space to development may reduce local recreation and cultural activities, increase traffic congestion, increase urban runoff and flooding, reduce water quality, and disturb, pollute or destroy natural habitats for wildlife.

Open space takes many forms. City parks provide some types of recreational and visual amenities. Greenbelts and ecological reserves typically are larger, often natural, open space areas that provide a broad range of services. The experience of cities with ambitious open space policies, such as Portland, Oregon and Boulder, Colorado, suggests that such policies have a significant effect on property values. Preserving land for open space affects property values in two important ways. First, it directly affects property values by restricting the supply of land for development. Second, open space designation and the associated amenities make certain areas more attractive, thereby changing the spatial patterns of demand within a given metropolitan area and potentially shifting the overall demand for housing by encouraging in- or out-migration. For this reason, spatially explicit models are needed to analyze the effect of open space designation on property values.

Spatially explicit models of land use in urban areas have been extensively investigated by urban and regional economists. The standard version of these models features a monocentric city built on a "featureless plain" with all jobs located in the city center. Households choose the location that provides the best tradeoff between land costs and transportation costs. Because transportation costs increase for locations farther from the city center, housing prices fall as the distance from the city center increases, compensating suburban workers for their increased costs of commuting. The model has been applied in a number of settings, and also extended to include amenities.[3] Brueckner et al. (1999) and Polinsky and Shavell (1976) analyze amenities that vary with distance to the city center. Yang and Fujita (1983) analyze the competitive and efficient solutions of an urban land market with open space and Lee and Fujita (1997) examine the efficient configuration of greenbelts. Wu (2001) and Wu and Plantinga (2003) develop a more general spatial equilibrium model to analyze the effect of spatial heterogeneity in amenities on development patterns.

There is a large body of literature that estimates the effect of amenities (or disamenities) on nearby property values. For example, the hedonic price model has been applied to estimate the value of proximity to oceans, lakes or rivers (Lansford and Jones 1995, Leggett and Bockstael 2000), urban parks and forests (Weicher and Zerbst 1973, Tyrväinen and Miettinen 2000), urban wetlands (Doss and Taff 1996, Mahan, Polasky, and Adams 2000), and general indicators of open space (Cheshire and Sheppard 1995, Geoghegan, Wainger, and Bockstael 1997, Irwin and Bockstael 2001, Riddel 2001, Geoghegan 2002, Irwin 2002).

In this paper we apply an urban equilibrium model to estimate the effect of open space and other amenities on property values and development density. The urban equilibrium model includes the interrelationships between households' residential choice decisions and developers' development decisions and emphasizes the importance of spatial heterogeneity in amenities in the formation of development patterns and property values. Equilibrium in the housing market is defined by three interdependent expressions for housing price, development density, and house size. These expressions are the basis for an empirical application of the model. Using data on Portland, Oregon, we estimate a system of simultaneous equations satisfied by equilibrium in the housing market. Our empirical model includes a large number of spatially-explicit variables to control for the heterogeneous open space amenities in the study area.

This study extends the previous literature in three important ways. First, it assumes that household utility is affected not only by exogenous environmental amenities (e.g., river view) that are out of the developers' control but also by endogenous "development amenities" (e.g., development density) that are determined by developers. Previous studies either ignore amenities or treat them as exogenous to the developers' decisions. Second, the paper presents a systems approach to estimate the effect of amenities on housing prices. This approach takes into account the endogenous nature of certain amenities. Previous hedonic studies ignore the endogenous nature of development amenities and regress property values directly on structural variables (e.g., lot size and square footage). Failure to account for endogeneity will result in inconsistent results if housing prices and lot size are simultaneously determined. Finally, we provide a rigorous theoretical foundation for variable choice in our model of residential housing prices.

II. The Model

In this section we present a conceptual model of residential development to motivate our empirical study. We start by extending the standard residential decision model to include the spatial heterogeneity of amenities and then model developers' residential development decisions. The first-order conditions for home buyers and developers are used to define equilibrium in the housing market.

The household decision model conforms to some of the basic assumptions of the standard monocentric city model, including a central business district (CBD) and commuting costs that depend on the residence-to-CBD distance. The landscape is represented by a Cartesian coordinate plane R^2, with the CBD located at the origin (0,0) and the *x*- and *y*-axis representing west-east and north-south directions, respectively. However, in contrast to traditional models, we allow residential sites to be differentiated by the level of environmental amenities. Residential houses are located across the plane, and are characterized by an individual vector of environmental amenities associated with a specific location (e.g., view), $a(x, y)$, and a vector of development amenities (henceforth referred to as the development density), $d(x, y)$. Households take both types of amenities as given when choosing residential locations, but developers can change the level of development amenities.

Households have preferences defined over the residential space (floor space) q, development and environmental amenities at their dwelling site, $d(x, y)$ and $a(x, y)$, and the consumption of a composite non-housing numeraire good z.[4] Following Solow (1973) and others, we assume that the household utility function takes a logarithmic form, but extend it to include amenities. Specifically, the utility function is assumed to be $U(q, z, d(x, y), a(x,y)) =$ $\alpha \ln q + \beta \ln z + \lambda \ln d(x, y) + \gamma \ln a(x, y)$, where α, β, λ, and γ are positive parameters with

$\alpha + \beta = 1$. This specification implies that amenities and residential space are substitutable; a small house with better amenities may provide the same level of utility as a larger house with less desirable amenities.

Each households chooses its most preferred combination of residential space (q) and composite good (z), and the residential location (x, y) to maximize utility subject to a budget constraint:

$$\begin{aligned} &\max_{\{q,z,x,y\}} \quad U = \alpha \ln q + \beta \ln z + \lambda \ln d(x,y) + \gamma \ln a(x,y) \\ &s.t. \qquad\qquad p(x,y)q + z + t(r) \leq m \end{aligned} \quad . \tag{1}$$

where $p(x,y)$ is the unit price for housing (dollars per square foot), m is the household's income, and $t(r)$ is the transportation cost function where $r = \left(x^2 + y^2\right)^{0.5}$ is the distance from the residential site (x, y) to the CBD. The first-order conditions for the maximization problem (1) yield the optimal choices of residential space and the non-housing good:

$$q^*(x,y) = \frac{\alpha[m - t(r)]}{p(x,y)}, \tag{2}$$

$$z^*(x,y) = \beta[m - t(r)]. \tag{3}$$

In a spatial market equilibrium, two conditions must be satisfied: housing prices must equate demand for and supply of housing, and households must have no incentive to change locations. To ensure that the second of these conditions is satisfied, we assume that costless migration occurs between cities.[5] In this case, migration equalizes utility across cities in equilibrium and, the utility level, denoted $\bar{u}$, is exogenous from the perspective of a single city. By imposing this condition, we can express the demand for housing solely in terms of price and the exogenous utility level. Substituting (2) and (3) into the utility function, setting utility equal to $\bar{u}$, and solving for price yields the "bid-price function" for housing:

$$(4) \qquad p^*(x,y) = p_0 d(x,y)^{\frac{\lambda}{\alpha}} a(x,y)^{\frac{\gamma}{\alpha}} [m - t(r)]^{\frac{1}{\alpha}} ,$$

where $p_0 = \alpha\beta^{\beta/\alpha} e^{-\bar{u}/\alpha}$ is a constant. Equation (4) is the price households are willing to pay for a unit of housing at location (*x*, *y*). When prices vary by (4) across the landscape, household utilities are identical across locations and households have no incentive to move.

The housing price function (4) reveals the difference between our model and the standard monocentric city model. In the standard model, environmental amenities are assumed to be distributed uniformly across the landscape. In this case, equation (4) indicates that housing prices always fall with the distance from the CBD, compensating suburban residents for their cost of commuting. However, with spatial variations in amenities, the spatial pattern of housing prices is more complicated. A household may be willing to sacrifice proximity to the workplace for local amenities, with the result that willingness to pay for housing may no longer be a monotonically decreasing function of CBD distance.

On the supply side, housing is produced with land, labor and materials under constant returns to scale. The developers' per-acre development costs are assumed to be $c(d,s,x,y) = c_0(x,y)d^{\delta}q^{\phi}$, where *d* is the development density (the number of houses per acre), and *q* is the house size (floor space, or square footage per house), parameters δ and ϕ are greater than one, and $c_0(x,y)$ reflects the effect of location on construction costs. At each location, the developer chooses the development density and the house size to maximize profit:

$$(5) \qquad \max_{d,q} \ \pi(d,q,x,y) = p^*(x,y)dq - c_0(x,y)d^{\delta}q^{\phi} .$$

The first-order conditions for this maximization problem are:

$$(6) \qquad \frac{\partial \pi}{\partial d} = p^* q + \frac{\partial p^*}{\partial d} dq - c_0(x,y)\delta d^{\delta-1}q^{\phi} = \left(\frac{\alpha+\lambda}{\alpha}\right) p^* q - c_0(x,y)\delta d^{\delta-1}q^{\phi} = 0 ,$$

(7) $$\frac{\partial \pi}{\partial q} = p^* d - c_0(x,y) d^{\delta} \phi q^{\phi-1} = 0,$$

where the derivation of (6) makes use of the result, from (4), $\partial p^* / \partial d = \lambda p^* / \alpha d$.

These first-order conditions yield the following relationships between development density, house size, and housing price:

(8) $$d = \left(\frac{\alpha+\lambda}{\delta\alpha}\right)^{\frac{1}{\delta-1}} c_0(x,y)^{-\frac{1}{\delta-1}} p^{*\frac{1}{\delta-1}} q^{\frac{1-\phi}{\delta-1}},$$

(9) $$q = [\phi c_0(x,y)]^{-\frac{1}{\phi-1}} p^{*\frac{1}{\phi-1}} d^{\frac{1-\delta}{\phi-1}}.$$

Both density and house size are functions of housing price and, through prices, the level of amenities at each location. Further, an increase in housing price would increase the development density and the square footage of each house built. If development density is a disamenity for households (i.e., $\lambda < 0$), however, then (4) indicates that an increase in development density will reduce households' willingness to pay for housing. Thus, the developer must balance the number of houses built and their size with price.

III. Empirical Specification and Estimation

Spatial equilibrium in the housing market satisfies (4), (8), and (9). These expressions provide the theoretical basis for an application to Portland, Oregon in which we econometrically analyze the effect of amenities on housing prices and development density. Taking logarithms of both sides of (4), (8), and (9), and assuming the same additive logarithmic structure for amenities, income, CBD distance, and factors affecting construction costs, we obtain the following system of simultaneous equations:

(10) Housing price: $$\ln p_i^* = \xi_0 + \xi_1 \ln d_i + \sum_{k=1}^{K} \xi_2^k \ln a_{ki} + \xi_4 \ln m_i + \xi_5 \ln r_i + \varepsilon_{1i},$$

(11) Household density: $$\ln d_i = \theta_0 + \theta_1 \ln p_i^* + \theta_2 \ln q_i + \sum_{k=1}^{K'} \theta_3^k \ln a'_{ki} + \varepsilon_{2i},$$

(12) House size: $$\ln q_i = \varsigma_0 + \varsigma_1 \ln p_i^* + \varsigma_2 \ln d_i + \sum_{k=1}^{K'} \varsigma_3^k \ln a'_{ki} + \varepsilon_{3i},$$

where i is an index of residential location, $(a_{1i}, a_{2i}, ..., a_{Ki})$ is a vector of environmental amenities at location i, $(a'_{1i}, a'_{2i}, ..., a'_{K'i})$ is a vector of physical variables that affect housing construction costs at location i, the ξs, θs, and ςs are parameters, and $\varepsilon_{1i}, \varepsilon_{2i}$, and ε_{3i} are error terms. To estimate the equation parameters in (10)-(12), we regress each of the endogenous variables on a set of instrumental variables, selected, in part, from the exogenous variables in the above equations.[6] From these auxillary regressions, we generate predicted values for the endogenous variables and substitute these into the right-hand sides of (10)-(12). For reasons discussed below, the density and size equations are estimated using only a subset of observations used to estimate the price equation. Since this results in unbalanced equations, the housing price equation is estimated separately from the density and size equations. As the errors in the two supply equations are likely to be contemporaneously correlated, these are estimated using the seemingly unrelated regression estimator.

At this stage, it is instructive to clarify the differences between our empirical model and hedonic price equations commonly estimated in the literature. The standard hedonic equation (or implicit price function) represents a locus of competitive equilibria between buyers and sellers in a housing market.[7] It is a reduced-form expression for the equilibrium price and, in most applications, modeling focuses on demand-side variables accounting for price differences, such as structural characteristics, neighborhood characteristics, and environmental amenities. In contrast, the bid-price function in (10) is a structural equation, specifically the inverse demand for a unit of housing at a specific location. As noted above, the bid-price function incorporates the equilibrium condition requiring household utilities to be constant across space. Equations (11) and (12) represent the supply side of the market—the density and size of houses that developers will supply given housing prices and construction costs. The demand and supply sides of the market come together in the system of simultaneous equations (10, 11, and 12). These equations are satisfied, according to our theoretical model, in a spatial market equilibrium. Housing prices, development densities, and house sizes are endogenously determined in the model.

Several econometric issues arise in the estimation of the equation system. One concerns the choice of functional form. The double-log specification is based on the theoretical model used here, which is built upon the assumption that the utility function is logarithmic (or Cobb-Douglas)[8], a commonly used functional form in the urban economics literature. However, since utility may not take the logarithmic or Cobb-Douglas form, it is useful to examine how sensitive the results would be to the specification of functional form.

A more general specification of functional form is the quadratic Box-Cox (Halvorsen and Pollakowski, 1981), which takes double-log, semi-log and several other functional forms as special cases. But an overly general specification may not prove robust to small mis-specification (Cassel and Mendelsohn, 1985; Cropper, Deck and McConnell, 1988). For example, Cropper, Deck and McConnell (1988) find that when variables are omitted or replaced by proxies, simpler forms such as linear or double-log perform better than more complex ones. Box and Cox warn against the use of the transformation when the transformed dependent variable is of primary interest, since any nonlinear transformation will introduce bias. Because of the problems associated with using complex functional forms, many studies assume a particular, simple functional form, such as linear, double-log, or semi-log in their hedonic analyses (see, e.g., Leggett and Bockstael, 2000; Tyrvainen and Miettinen, 2000; Halvorsen and Pollakowki, 1981). Following these studies, we consider three more functional forms; the semi-log (dependent variables in logarithms, and independent variables in linear forms), inversed semi-log (dependent variables in linear forms, and independent variables in logarithms), and linear (both dependent and independent variables in linear forms). Estimation results for these three specifications are qualitatively and statistically similar to the estimates, discussed below, for the double-log specification.

Multicollinearity poses another potential problem to the estimation of hedonic models, given that neighborhood characteristics are frequently correlated (Leggett and Bockstael, 2000). The major undesirable consequence of multicollinearity is that estimated coefficients for the collinear variables are unstable and have large variances. The solutions to the problem include dropping highly collinear variables from the model, obtaining more data, and formalizing relationships among regressors or parameters (Kennedy, 1998; pp. 187-88). To avoid the potential multicollinearity problem, variables that are highly correlated with other variables are dropped from our final model. In addition, a large number of observations are used in the estimation of our final model.

A final estimation issue concerns spatial autocorrelation. We must construct a number of variables with spatial dimensions—housing densities, availability and proximity to open space, distance to the city center, and so on. Failure to measure these variables in a way that accurately reflects the underlying spatial processes is likely to induce spatial dependence in the error terms. We test for spatial autocorrelation by computing Moran's *I* statistic for each equation, given by

$I = N(\hat{\boldsymbol{\varepsilon}}'\mathbf{W}\hat{\boldsymbol{\varepsilon}})/S(\hat{\boldsymbol{\varepsilon}}'\hat{\boldsymbol{\varepsilon}})$ where N is the number of observations, $\hat{\boldsymbol{\varepsilon}}$ is a vector of estimated residuals, **W** is a matrix indicating the spatial structure of the data, and S is a standarization factor equal to the sum of the elements of **W**. Each element of **W**, w_{ij}, is equal to one if the *i*th observation is in a zip code area that borders the zip code area for the *j*th observation and, otherwise, is equal to zero.[9]

As discussed below, we find evidence of spatial autocorrelation in all three equations. We assume the error structure in each equation is given by $\boldsymbol{\varepsilon} = \rho\mathbf{W}\boldsymbol{\varepsilon} + \boldsymbol{\upsilon}$ where ρ is a scalar and $\boldsymbol{\upsilon}$ is a vector of spherical disturbances with zero mean. We assume there is no cross-equation spatial dependence in the errors. To estimate ρ, we use the generalized moments estimator developed by Kelejian and Prucha (1999). Applying equation (7) in Kelejian and Prucha, we estimate ρ for each equation and transform the data with the matrix $\hat{\mathbf{P}} = \mathbf{I} - \hat{\rho}\mathbf{W}$, where **I** is the identity matrix.

IV. Study Area and Data

The study area is that portion of Multnomah county that lies within the Portland urban growth boundary. Multnomah county encompasses the city of Portland, the largest city in the state of Oregon, with a population of about 530,000 in 2000. Portland and the surrounding communities are located at the north end of the Willamette Valley and are noted for their generally high level of environmental amenities.

The data used in this study were obtained from several sources. Real estate data for Multnomah county were obtained from MetroScan, Sacramento, California, which collects real estate data from Assessor's records for numerous cities.[10] Metro Regional Services, a directly elected regional government agency for the greater Portland area, provided digital neighborhood and environmental characteristics for each residential property that was sold. Metro's ArcView geographic information system was used to calculate the percentages of land designated for alternative uses (e.g., parks and public open space, commercial use) within each zip code area. Distance calculations were made using a raster system where all data are arranged in grid cells. Each cell is 54-feet square. Distances were measured as the Euclidean distance in feet from the centroid of the tax lot to the nearest edge of the feature. Because information on household income is unavailable for individual households, median household income within each zip code area was used as a regressor. This information was obtained from the U.S. Census.

The variables used in this analysis, along with descriptive statistics for each, are provided in Table 1. Specifically, Table 1 presents descriptions of 19 amenity and house characteristic variables, of which three are the endogenous variables in the simultaneous equations system (housing price per square feet, house size, and development density). Categorical variables for location and amenity type are also included.

The housing price per square foot is obtained by dividing the actual sales price of a residence by the square footage of the house. Actual sales prices of individual properties are preferred to other forms of data on property values such as assessed, appraised or census tract estimates because they more accurately reflect homeowners preferences. A total of 14,485 market-based residential sales occurred in Multnomah county between June 1992 and May 1994.[11] Sales prices were adjusted by a price index for the Multnomah county residential housing market to a May 1994 price level. The average sales price is $75 per square foot, with an average square footage of 1426 square feet.

The amenity measures include elevation, proximity to natural and man-made features, such as rivers, parks, lakes, wetlands, and the central business district, and percentage of land designated as parks or public open space in the zip code area. Categorical variables relate to the location of the house within the metropolitan area and level of traffic. Other explanatory variables include income, proximity to industrial or commercial zones within the metropolitan area, and age of the house. The mean age of houses in the sample is approximately 45 years. This statistic raises an important issue about how to appropriately model the developer's decision.[12] In (11) and (12), density and house size are functions of house prices, which in our data are measured during the early to mid-1990s. Since developers are likely to base decisions on recent prices, we should model development decisions contemporaneous with the observed prices. Accordingly, we estimate (11) and (12) with data on houses less than five years in age. To take full advantage of variation in the housing price variable, all of the observations are used to estimate (10).

V. Results

The parameter estimates and summary statistics for the double-log specification of the simultaneous equation system are presented in Tables 2 and 3. Table 2 reports the parameter estimates for the households' bid-price function for housing (equation 10, with PRICE as the dependent variable) while Table 3 presents the supply equations as determined by the developer's decisions regarding the number of houses to build per acre (Equation 11, with DENSITY as the dependent variable) and the size of those housing units (Equation 12, with TOTAL SF as the dependent variable). As indicated above, spatial autocorrelation was detected and adjusted for in each of the equations. For the price, density, and size equations, respectively, the value of the Moran's *I* statistic, with the standard deviation following in parentheses, is 0.0036 (0.0003), 0.0055 (0.0026), and –0.0059 (0.0026). Assuming an approximate standard normal distribution for *I*, the null hypothesis of no spatial autocorrelation is rejected at the 5% level in each case. The estimated values of the spatial autocorrelation parameter ρ are, respectively, 1.41×10^{-7}, 3.55×10^{-6}, and -2.20×10^{-5}. In the final model, the equations have reasonable explanatory power (with respect to the transformed variables) and the coefficients in each equation are, with few exceptions, statistically significant at the 5% level. The signs of the coefficients are largely consistent with effects predicted by the theoretical model.

In Table 2, the relationships between the bid price for housing (represented as price per square foot) and the various amenities are statistically significant at the 5% level, except for slope and distance to rivers and commercial districts, and in almost all cases have the expected signs. Specifically, the results suggest that households are willing to pay more for newer houses located closer to areas of open spaces (e.g., near parks, lakes, wetlands) and in areas of less dense development (i.e., lower density). In addition, houses with better views (located at higher elevations) and located farther from industrial areas and in areas of less traffic congestion, are more highly valued.

The demand by residential house buyers for lower density housing, as reflected in the desire to be closer to "open space," and in the sign on the "DENSITY" variable, runs counter to recent land use policies adopted by the Metro Regional government (and most other western Oregon cities) to develop more houses per unit of land brought into development. The existence of government-mandated urban growth boundaries and higher density housing requirements in the Portland metropolitan area points to a fundamental conflict between home buyers' preferences and the societal desire to preserve open space on the city fringe.

Other amenity features have mixed effects on the willingness to pay for housing. For example, distance to commercial districts does not significantly affect housing prices. This result may reflect a combination of positive effects (proximity to shopping, restaurants, etc.) and negative effects (noise, incidental light, etc.). Being located within the Portland urban growth boundary has a positive effect on prices (all dummy variables for houses located within the designated Portland metropolitan boundary have positive values). These results indicate a preference for houses within the Portland city limits and again sets up potential development problems, given the incompatibility between an expressed desire on the part of home buyers for less density (larger lot size) and locations within the Portland metropolitan area.

The equations representing the developer's decision problem (of how many and what size house to supply) are contained in Table 3. Most of the coefficient estimates are significantly different from zero at the 5% level, particularly in the density equation. For the developer, increases in housing prices result in an attempt to provide more houses per unit area (i.e., the relationship between DENSITY and PRICE is positive) and large houses (PRICE has a positive effect on TOTALSF). The attempt to provide more houses, however, results in higher density, which will ultimately reduce prices since density is a disamenity for households (Table 2).

The effect of amenities differs in some cases between the developer and the consumer. For example, elevation increases consumers willingness to pay but reduces the number of houses supplied (as does slope) due to the effect on construction costs. The coefficients on the amount of nearby parks and open space (PARKOPEN) are negative in the density and size equations. At first glance, this result may seem counterintuitive since one would expect developers to increase density and house size in neighborhoods with desirable amenities. However, it is important to interpret these results holding prices constant. Controlling for the positive effect of PARKOPEN on density and size through the price variable, more parks and open space may simply decrease the remaining land available to build houses and, thus, lower densities and house sizes. The signs on most other variables can be explained either by their effect on construction costs or the price of undeveloped land. The size of houses is affected differently by some variables than is the decision regarding the number of houses to provide. That is, in some locations where construction or land costs are high, developers have an incentive to build larger but fewer homes per unit of land in order to maximize profits.

The simultaneous system of equations provides a framework with which to explore a range of policy questions concerning residential development patterns. To exploit the potential of the systems approach, the estimated structural equations for housing price, development density and house size are solved for their reduced-form equivalents. These reduced-form equations are then used to simulate the effect of changes in exogenous amenity variables on housing price, development density and house size. An advantage of the systems approach used here is that the reduced-form equations capture both the direct effects of an amenity variable on an endogenous variable as well as indirect effects through other endogenous variables. Some of the potential effects of such changes are presented in Table 4.

The simulation results from Table 4 show that an increase in elevation (by 100 feet) reduces development density (by 261 units per square mile) and increases house size (by 42 square feet) and housing price (by $2.12 per square foot). Because buyers are willing to pay a higher price for a house with a better view and larger lot, developers tend to build fewer but larger houses in scenic hill locations surrounding the city. An increase in parks and open space by 5 percent increases house prices, reduces density, and has a negligible effect on house size. These amenities (and others in the table) increase housing price both directly, through willingness to pay, and indirectly through effects on development density. The negative reduced-form effect of parks and open space on density indicates that positive effects on density (e.g., those transmitted through prices) are outweighed by negative direct effects potentially related to land availability and negative indirect effects transmitted through the size equation.

The results of Table 4 can also suggest the value of public investments or land use policies. For example, traffic congestion has a substantial effect on house prices (reduces price by nearly $3.00 per square foot). Thus, for the average house size (of approximately 1500 square feet), transportation planning which reduces congestion (by one category within the ranking used here) would increase house prices by $4500 per household. Similarly, zoning or other policies which increase land in open space by 5 percent increases the willingness to pay for housing by $0.71 per square foot and the house value by approximately $1,000. These increases translate into increased property tax revenue which in turn may pay for such public investments in structural or operational measures. Similar calculations can be performed for other amenities.

VI. Concluding Comments

This paper develops and applies an amenity-based urban equilibrium model to analyze the effect of open space and other amenities on housing prices, development densities, and house sizes. By explicitly incorporating household and developer decisions into the estimation framework, both direct and indirect effects of amenities on the housing market can be obtained. Further, we can represent development density as an endogenous process, in contrast to standard hedonic analyses which treat density as exogenous. The model is applied to the Portland, Oregon metropolitan area, a region of rapid population growth and where concerns over "quality of life" issues frequently enter policy debates concerning growth.

Results from the empirical analysis are largely consistent with our theoretical model and are robust to alternative specifications of the functional form. The estimation results from the structural relations indicate households willingness to pay for a range of amenities, including more parks and open space. Conversely, developers tend to respond to higher prices with more houses per unit of land. Reduced-form equations are used to perform hypothetical policy simulations on a number of the amenity variables. The ability to perform such simulations supports the usefulness of a systems approach to the measurement of open space values. From a policy perspective, the structural relationships and reduced-form simulations point to conflicts between household preferences and societal desires to reduce the conversion of open space to housing. Failure to recognize these differences between house purchaser preferences and those of land developers will reduce the effectiveness of zoning and other land use planning mechanisms.

A natural extension of our modeling framework is to estimate the welfare effects of changes in amenity levels. It is well known that hedonic price functions can be used for benefit estimation only under strong restrictions, including the assumption that changes in amenities do not affect developers' costs of supplying housing. This assumption is not supported by our results, which reveal housing supply to depend significantly on amenity variables. In general, welfare analysis requires knowledge of the structural demand and supply relationships, which we estimate explicitly with this approach. Additional research is needed to determine if and how the estimated relationships can be used to derive consumer and producer surplus measures. If this is possible, then our framework can be used for comprehensive benefit-cost analysis of prospective land use policies.

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TABLE 1. VARIABLES AND DESCRIPTIVE STATISTICS

Variable	Description	Mean	Std. Dev.	Min	Max
PRICE/SF	Housing price per square foot ($/sf)	75	25	6	385
TOTAL SF	Total structure square footage	1426	574	364	8099
DENSITY	Development density as measured by the number of houses per square mile	4471	1803	63	28950
ELEVATE	Elevation of property above see level in feet	265	143	0	1200
PARKOPEN	Percent of land designated as parks or public open space within a zip code area	0.09	0.05	0.00	0.24
PARK_DS	Distance in feet to nearest improved public park	1345	869	0	5553
RIVER_DS	Distance in feet to nearest river	6612	4057	0	18289
LAKE_DS	Distance in feet to nearest lake	17701	6793	0	35535
WTLD_DS	Distance in feet to nearest wetland of any type	3589	2481	52	11930
SLOPE	Slope of property as a percent	5	12	0	350
INDUS_DS	Distance in feet to nearest industrial zone	3675	2970	0	15321
COMM_DIS	Distance in feet to nearest commercial zone	1284	1872	0	73030
DLTTRAF	Dummy for traffic (1 if light traffic, 0 otherwise)	0.91	0.28	0.00	1.00
HOUSE AGE	Year house was built subtracted from 1994	44.52	26.94	0.00	114.00
INCOME	Median household income within zip code area	35162	7935	21689	62012
CBD	Distance in feet to central business district	31605	18003	73	79206
TRANS_DS	Distance in feet to nearest public transportation	1376	1181	0	13895
DSW	Dummy for property location (1 if located in southwest Multnomah County)	0.18	0.39	0.00	1.00
DSE	Dummy for property location (1 if located in southeast Multnomah County)	0.38	0.49	0.00	1.00
DNW	Dummy for property location (1 if located in northwest Multnomah County)	0.03	0.16	0.00	1.00
DNE	Dummy for property location (1 if located in northeast Multnomah County)	0.32	0.47	0.00	1.00

TABLE 2. HOUSING PRICE FUNCTION ESTIMATES FROM THE SIMULTANEOUS DOUBLE-LOG EQUATION SYSTEM

Variables	Coefficient	t-statistic
Endogenous Variables		
Ln(DENSITY)	-0.329*	-11.85
Exogenous Variables		
INTERCEPT	4.532*	9.46
Ln(ELEVATE)	0.021*	3.10
Ln(PARKOPEN)	0.014*	3.64
Ln(PARK_DS)	-0.006*	-2.48
Ln(RIVER_DS)	-0.002	-0.47
Ln(LAKE_DS)	-0.068*	-15.01
Ln(WTLD_DS)	-0.009*	-2.88
Ln(SLOPE)	-0.0002	-0.68
Ln(INDUS_DS)	0.017*	7.86
Ln(COMM_DS)	0.0002	0.18
Ln(TRANS_DS)	0.006*	3.64
DLTTRAF	0.050*	6.36
Ln(HOUSE AGE)	-0.011*	-11.74
Ln(INCOME)	0.437*	20.01
Ln(CBD)	-0.163*	-20.59
DSW	0.043*	2.92
DSE	0.136*	14.84
DNW	0.176*	9.61
DNE	0.120*	12.21
Number of Observations	14191	
Adjusted R-Square	0.18	

* denotes significance at the 5% level.

TABLE 3. DEVELOPER SUPPLY FUNCTION ESTIMATES FROM THE SIMULTANEOUS DOUBLE-LOG EQUATION SYSTEM

	Ln(DENSITY)		Ln(TOTAL SF)	
	Coefficient	t-statistic	Coefficient	t-statistic
Endogenous Variables				
Ln(PRICE)	0.691*	9.66	0.666*	15.34
Ln(TOTAL SF)	-0.939*	-16.42		
Ln(DENSITY)			-0.525*	-17.15
Exogenous Variables				
INTERCEPT	12.019*	30.22	8.525*	24.65
Ln(ELEVATE)	-0.088*	-6.23	0.052*	5.16
Ln(PARKOPEN)	-0.043*	-2.08	-0.030*	-1.97
Ln(PARK_DS)	0.008	1.52	0.007	1.90
Ln(RIVER_DS)	0.069*	10.19	0.003	0.56
Ln(LAKE_DS)	-0.039*	-2.77	-0.008*	-0.78
Ln(WTLD_DS)	0.051*	8.58	-0.002	-0.50
Ln(SLOPE)	-0.002*	-2.54	0.002*	3.54
DSW	-0.001	-0.01	0.016	0.43
DSE	-0.104*	-2.05	-0.082*	-2.22
DNW	0.324*	5.50	0.145*	3.40
DNE	-0.090	-1.83	0.048	1.33
Number of observations	1334		1334	
R-square	0.19		0.42	

* denotes significance at the 5% level

TABLE 4. ESTIMATED EFFECTS OF AMENITIES AND OTHER VARIABLES ON HOUSING PRICE, DEVELOPMENT DENSITY, AND HOUSE SIZE

	Changes in		
An increase in [a]	Housing Price ($\$/ft^2$)	Development Density ($\#/mi^2$)	House Size (ft^2)
Elevation by 100 feet	2.39	-330	129
Percent land area in parks and open space by 5%	0.73	-50	0
Distance to nearest park by 1000 feet	-0.24	5	2
Distance to nearest river by 1000 feet	-0.42	74	-19
Distance to nearest lake by 1000 feet	-0.18	-15	0
Distance to nearest industrial zone by 1000 feet	0.27	2	4
Distance to nearest commercial zone by 1000 feet	0.00	0	0
Distance to nearest wetland by 1000 feet	-0.71	104	-30
Distance to public transportation by 1000 feet	0.20	2	3
Distance to the CBD by one mile	-1.67	-13	-22
Traffic from "light" to "heavy"	-3.26	-26	-43
House age by 10 years	-0.15	-1	-2
Median household income by $5000	3.98	30	51

[a] All other variables are set at the mean values when the effect of each change is calculated.

Footnotes

[1] Eleven million acres of farmland, forest, and open space were converted to development between 1992 to 1997 in the U.S. (U.S. Department Agriculture 2001). The average rate for those five years is nearly double that recorded from 1982 to 1992. From 1982 to 1997, the total acreage of developed land increased by more than 25 million acres, or one-third (34 percent).

[2] Public opinion polls confirm that there is strong public support for growth management. For example, a 2000 poll commissioned by Smart Growth America found that 78 percent of Americans support policies to slow urban expansion. A 1999 poll, commissioned by Americans For Our Heritage and Recreation and The Nature Conservancy, finds that even in areas where the federal government already owns a large percentage of the land base, there is public support for purchasing land for conservation. A poll, conducted for the Trust for Public Land, shows that a clear majority of voters from both parties feel government efforts to protect land from development are inadequate.

[3] For example, Carpenter and Heffley (1982) use such a model to analyze the effect of transferable development rights on housing rents and property-tax revenue; White (1975) assesses the effect of zoning on the size of metropolitan areas; McMillen and McDonald (1993), and Grieson and White (1981) evaluate the effect of zoning on property values. Additional extensions of the model examine the effect of different income groups, zoning, imperfect housing markets, and multiple employment centers. For a review, see Anas et al. (1998).

[4] We assume that utility depends on development density and amenities at location (x,y), rather than on densities and amenities in the neighborhood of (x,y). This is done to simplify the analytics. However, in the empirical application, we include more general measures of neighborhood characteristics.

[5] An open city model is adopted here because the degree of household mobility has implications for the validity of cross-section regression results to predict property value adjustments in responses to changes in the spatial patterns of amenities (Polinsky and Shavell, 1976). As shown by equation (4), below, in an open city with perfect mobility, the utility level is exogenously determined, and housing prices at any location depend only on amenities at that location. In this case, cross-section regression results can be used to predict property value adjustments in response to changes in amenities. However, in a closed city, housing prices at any location depend on amenities throughout the city because the utility level depends on amenities throughout the city. As a result, cross-section regression results cannot be used in a direct way to predict property value adjustments. Polinsky and Shavell (1976) suggest that the open city model may be applied to small communities in a large urban area where there is a high degree of mobility, which is the case of Portland, Oregon.

[6] The instrumental variable results are not reported, but are available from the authors upon request.

[7] For a review of the hedonic price method, see Freeman (1993).

[8] Because the logarithmic functional form is a logarithmic transformation of the Cobb-Douglas form, all theoretical results hold if the utility function is assumed to take the Cobb-Douglas functional form.

[9] The choice to delineate "neighborhoods" using zip code boundaries is somewhat arbitrary. Zip codes are a convenient choice since several variables are delineated in this fashion and because other choices (e.g., townships) results in extreme differences in levels of aggregation.

[10] We thank Brent Mahan of the U.S. Army Corps of Engineers for making available the real estate data.

[11] We have complete observations of all the variables used in the analysis for 14,191 of these sales.

[12] We are indebted to a referee for pointing this out.