

# Accounting for Heterogeneity of Public Lands in Hedonic Property Models

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**ABSTRACT.** *Open space lands, national forests in particular, are usually treated as homogeneous entities in hedonic price studies. Failure to account for the heterogeneous nature of public open spaces may result in inappropriate inferences about the benefits of proximate location to such lands. In this study the hedonic price method is used to estimate the marginal values for proximity to the Pike National Forest. The results indicate that specifying the forest as homogeneous overstates the benefits for homes within two miles relative to specifying the forest based on land use characteristics, because the significant negative effect from noise-intensive activities is omitted. (JEL H41, Q51)*

## I. INTRODUCTION

Living proximate to public lands provides amenities such as convenient access to recreation and wildlife viewing, as well as disamenities such as crowds, litter, and noise (Garber-Yonts 2004; Bolitzer and Netusil 2000; Moore et al. 1992). National forests are particularly heterogeneous with respect to provision of amenities and disamenities, as these forests are often thousands or even millions of acres in size and allow multiple uses. In general, hedonic studies have found a positive effect on sales prices of homes located near national forest lands (Cho et al. 2009; Hand et al. 2008; Kim and Johnson 2002; Shultz and King 2001). However, a few recent studies have found negligible or negative price effects of living near a national forest (Kling et al. 2007; Mueller and Loomis 2008). For example, in a study that considered different kinds of open space at the rural-urban fringe in Larimer County, Colorado, no price

effect was found for homes proximate to the Arapaho-Roosevelt National Forest for the majority of model specifications. The authors posit that this result could be due to the relative abundance of substitutes and uncertainty about potential negative externalities from national forest land uses (Kling et al. 2007). Mueller and Loomis (2008) found negative price effects of being proximate to the Angeles National Forest in California after two wildfire events in that forest.

In these past studies, a national forest was considered a homogeneous entity and distance was measured from a housing area to a forest boundary. However, this homogeneous land use representation in the model does not reflect the multiple-use management approach required of the U.S. Forest Service under the mandate of the 1976 National Forest Management Act. The Forest Service “working lands” are managed for specific resource uses including wildlife, timber, water quality, range, and recreation. Thus, living near active timber management or motorized recreation areas might be undesirable relative to living by wildlife habitat or hiking trails. Many past studies of national forests have not included this spatial heterogeneity and treated the forest as one homogeneous unit of public land.

We hypothesize that some of the divergent findings with respect to the influence of proximity to national forests on property values arise from a failure to differentiate a prop-

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erty's distance to different land uses. To test our hypothesis, we compare the approach of representing a national forest as homogenous with one that differentiates proximity to quiet recreational areas and noisier areas of the national forest. This approach allows us to evaluate whether spatial heterogeneity matters in calculating implicit values. Specifically, we use the hedonic approach to estimate the marginal values associated with living proximate to the Pike National Forest under the standard assumption of the forest as a homogenous land entity. Then, we examine the marginal values when proximity to recreation opportunities (e.g., roaded natural and rural recreation areas) are differentiated from proximity to noisy activities (areas that allow off-road vehicles, logging activities, etc.). This approach allows us to tell a more nuanced story about the relationship between the Pike National Forest and proximate home values. Whether it is good or bad to live near the Pike National Forest may depend on whether one lives near land uses that are quiet and scenic, like hiking trails, or something noisy, like an off-road vehicle trail.

## II. METHODS

The hedonic method is a revealed preference nonmarket valuation approach that uses information from actual market transactions to infer the values consumers place on attributes of a good (Rosen 1974). Applications of the hedonic method to housing are common and often applied to estimate values of environmental amenities such as open space for inclusion in policy analysis (McConnell and Walls 2005). A review of the hedonic method for nonmarket valuation can be found in works by Freeman (2003), Taylor (2003), Palmquist (2005), and Bockstael and McConnell (2007). In the housing market, the equilibrium hedonic price function is determined by the interaction of utility-maximizing house buyers and profit-maximizing house sellers. The house, the optimal consumption bundle, is an envelope function where marginal bids and marginal offers equal the marginal prices for house characteristics. The theoretical specification for the hedonic price function defines the vector of house sales prices ( $\mathbf{P}$ ) as a func-

tion of the individual characteristics of the houses according to four categories in matrix form: structural components of the houses ( $\mathbf{S}$ ), neighborhood demographic variables ( $\mathbf{N}$ ), location-specific attributes ( $\mathbf{L}$ ), and time ( $\mathbf{T}$ ).

$$\mathbf{P} = f(\mathbf{S}, \mathbf{N}, \mathbf{L}, \mathbf{T}; \alpha, \beta, \gamma, \delta), \quad [1]$$

$$\ln \mathbf{P} = \alpha \mathbf{S} + \beta \mathbf{N} + \gamma \mathbf{L} + \delta \mathbf{T} + \varepsilon, \quad [2]$$

$$\varepsilon \sim N(0, \sigma^2 I_n), \quad [3]$$

where the estimated parameters ( $\alpha$ ,  $\beta$ ,  $\gamma$ ,  $\delta$ ) describe the relationships between house prices and the measures included within the four categories. The incremental change in the price of the house represents the additional amount house buyers are willing to pay for a marginal change in the attribute, holding all the other attributes constant. The error term is assumed to be independent and identically distributed.

Cropper, Deck, and McConnell (1988) provide a comparison of possible choices for functional forms and suggest the semilog model is a robust functional form to the omitted variables problem common in hedonic property models. In this study, the log transformation of the dependent variable is chosen to minimize heteroskedasticity (Wooldridge 2003) and because the sales data have a long right-side tail. If the individual characteristic of the house is measured as continuous, the estimate describes the direction, magnitude, and significance of the change in the house price for one more unit. If the characteristic is represented using a dummy variable, the estimate describes the change in the house price based on including the characteristic, such as if the house was new when sold. Thus, because marginal effects of the determinants of house prices may vary with the price level of the house, the double log functional form is chosen for distances, areas, and income levels, except for garage and basement areas that may not exhibit similar diminishing returns (Iwata, Murao, and Wang 2000; Mahan, Polasky, and Adams 2000; Bin and Polasky 2004).

Implicit prices for each house attribute included in the hedonic price function can be

calculated using the coefficient estimates (Taylor 2003). The exact implicit price calculation depends on the functional form of the dependent and independent variables, along with any adjustments for neighborhood effects that will be addressed in the section on spatial considerations. Assuming a log-dependent variable and an independent variable specified as linear, the implicit price is the estimated coefficient times the mean house price. For independent variables specified using the logarithmic transformation, the implicit price is the estimated coefficient times the average house price divided by the average value for the independent variable in question. Finally, for variables that represent discrete characteristics using dummy variables, the implicit price is the exponential value of the coefficient minus one, then multiplied by the average house price. With the estimated implicit prices, the relative contribution of each variable included in the model can be stated as a percentage of the total average house price to indicate the relative importance of that variable to the total value of the house.

This first stage to modeling demand preferences is sufficient for answering questions at the margin, such as what magnitude, direction, and significance does an additional unit of some attribute add or detract from the sales price of a home. In this study, we are interested in the marginal values of homes located closer to the Pike National Forest, so the first-stage analysis is sufficient. Second-stage hedonic analysis utilizes implicit prices from the first-stage analysis, along with observed quantities purchased and demographic information, to recover inverse demand functions for the house characteristics to calculate the welfare effects of nonmarginal changes.

However, many econometric issues arise when estimating the first-stage hedonic price models that can either bias the coefficient estimates or simply result in less efficient estimators. A few examples are a high degree of collinearity among independent variables, spatial dependence and omitted variables within the housing market, and endogeneity of housing prices and land availability (Irwin and Bockstael 2001; Irwin 2002). By examining the correlations among the independent

variables, particularly the Pike National Forest distance measures, along with variance inflation factors, the subset of variables is chosen to reduce multicollinearity (Belsley, Kuh, and Welsch 2005). Spatial considerations are addressed in the next section, while endogeneity of housing prices and land availability are modestly addressed using market timing variables to represent the variation in sales annually.

### Spatial Considerations

Spatial dependence occurs when observations across space are systematically related. The interconnection is more formally called spatial autocorrelation and a direct result of Tobler's (1979) first law of geography that states "everything is related to everything else, but near things are more related than distant things." One form of spatial dependence in hedonic price models occurs when house prices are based on comparable homes in the immediate vicinity such as within a half mile. The justification for using neighboring values in the calculation is that homes share the value of being located in a particular place such as near common environmental amenities or public services. A second form of spatial dependence, called spatial error dependence, may occur when an omitted variable is also correlated with the error of its neighbor, and it is similar to serial correlation in time series data. Spatial error can also be due to measurement errors that may occur with overlapping data layers from multiple data sources or generally when the variable is hard to measure. We examine each spatial component separately and jointly using the spatial statistics software, R (R Development Core Team 2005).

### Spatial Lag Models

In the real estate industry it is common practice to assess a property's value based on the prices of nearby homes (Can 1990). This process justifies the need to include a measure that specifies the interconnection between houses in close proximity through the form of

a spatially lagged dependent variable. The spatially lagged dependent variable is composed of a spatial lag parameter,  $\rho$ , and a spatial weighting matrix,  $\mathbf{W}$ . To determine if significant spatial autocorrelation exists due to the influence of neighbors, we look at the ordinary least squares (OLS) residuals of the standard hedonic price model. Erroneously omitting the spatial lag term leads to biased and inconsistent estimation of coefficients (Anselin 1988). If a spatial pattern is in the residuals of the OLS model, then we want to include the information as an additional explanatory variable. In matrix form,

$$\ln \mathbf{P} = \rho \mathbf{W} \mathbf{P} + \alpha \mathbf{S} + \beta \mathbf{N} + \gamma \mathbf{L} + \delta \mathbf{T} + \varepsilon. \quad [4]$$

If spatial autocorrelation is significant, the lagged dependent variable,  $\rho \mathbf{W} \mathbf{P}$ , provides spatial structural information to the model, thus reducing omitted variable bias and improving efficiency of estimators. If  $\rho$  is statistically different from zero, then the spatial multiplier,  $1/(1 - \rho)$ , is needed to adjust coefficient estimates to reflect the marginal values that are related to location, in addition to the marginal value of the characteristic (Kim, Phipps, and Anselin 2003). Alternatively, if the spatial weight matrix adequately accounts for the spatial lag effect, then  $\rho$  may be insignificant while the inclusion of the lagged variable significantly improves the model fit (Anselin 2005).

To estimate the spatial models, the researcher must specify a spatial weight matrix that captures the spatial dependence expected in the data. For example, spatial dependence between objects of analysis may occur based on Euclidean distance (actual or perceived), distance by road, travel time, number of nearest neighbors, or a river network. The spatial weight matrix ( $\mathbf{W}$ ) in equation [5] represents the expected relationship between house  $i$  and house  $j$ .

$$\mathbf{W} = [w_{ij}]_{i,j=1}^n. \quad [5]$$

The data for hedonic price models are expected to exhibit a spatial lag, and the process for selecting the spatial weight involves including the prices of houses within various distance ranges to see if inclusion of neigh-

borhood price structure reduces the spatial autocorrelation. The form of the spatial weights used for this study is shown in equation [6]. The spatial weights are created using inverse distance weighting, also called distance-decay, which allows for homes closer to each other to have a greater influence in the estimation process up to some distance ( $b$ ).

$$w_{ij} = \begin{cases} \frac{1}{d_{ij}}, & \text{if } d_{ij} \leq b \\ 0, & \text{otherwise} \end{cases}. \quad [6]$$

To determine the distance ( $b$ ), one examines the semivariogram of the residuals from the OLS regression estimation of the hedonic price function to learn more about the patterns in the residuals that are related to distance (Cressie 1993). With more information about patterns in the residuals, the spatial weight matrix that accounts for the spatial autocorrelation can be constructed. The weight matrix is row-standardized so that the parameter coefficients for the spatial components are bound by  $-1$  and  $1$  (equation [7]).

$$\bar{w}_{ij} = \frac{w_{ij}}{\sum_{j=1}^n w_{ij}}. \quad [7]$$

### Spatial Error Models

A second spatial relationship that needs to be considered in the model is caused by misspecification. The misspecification may be due to improper functional form, measurement error in the variables included, or omitted variables due to challenges in measuring the concept. The original error term from OLS is modeled as an autoregressive error term where  $\varepsilon$  denotes the residual matrix,  $\mathbf{W}$  is a spatial weighting matrix, and  $\lambda$  is the coefficient. In matrix form,

$$\ln \mathbf{P} = \alpha \mathbf{S} + \beta \mathbf{N} + \gamma \mathbf{L} + \delta \mathbf{T} + \varepsilon, \quad [8]$$

$$\varepsilon = \lambda \mathbf{W} \varepsilon + v. \quad [9]$$

The transformed residuals  $v$  are independently distributed about a mean of zero.

**Joint Spatial Lag and Spatial Error Models**

Finally, the joint model that includes both the spatial lag and the spatial error components is specified by

$$\ln P = \rho WP + \alpha S + \beta N + \gamma L + \delta T + \varepsilon, \quad [10]$$

$$\varepsilon = \lambda W \varepsilon + v. \quad [11]$$

For the joint spatial model, the values of  $\rho$  and  $\lambda$  are simultaneously estimated by the maximum likelihood method. If  $\rho$  is significant, coefficient estimates in the joint model will also need to be adjusted using the spatial multiplier.

The test statistics used to determine whether spatial autocorrelation exists are (1) Moran's  $I$  and (2) the Lagrange multiplier (Anselin and Rey 1991). Moran's  $I$  test statistic (equation [12]) is used to determine whether spatial autocorrelation exists, where  $N$  is the number of houses indexed by  $i$  and  $j$ ,  $X$  is the variable of interest,  $\bar{X}$  is the mean of  $X$ , and  $w_{ij}$  is the spatial relationship between house  $i$  and house  $j$ .

Moran's  $I$ :

$$I = \frac{N}{\sum_i \sum_j w_{ij}} \frac{\sum_i \sum_j w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2}. \quad [12]$$

The Lagrange multiplier test statistic (equation [13]) relays information about local (smaller-scale) variability and the need for a lagged dependent variable where spatial correlation is rejected if

$$\left[ \frac{n \hat{\varepsilon}' W \hat{\varepsilon}}{\hat{\varepsilon}' \hat{\varepsilon} \text{tr}(W^2 + W'W)^{\frac{1}{2}}} \right]^2 > \chi^2_{1,0.95} = 3.84. \quad [13]$$

Then, the model with the smallest Akaike information criterion (AIC) is deemed the most appropriate model for hypothesis testing (Jones, Leishman, and Watkins 2003).

**III. STUDY AREA AND DATA**

El Paso County, Colorado, is located along the eastern edge of the southern Rocky Moun-

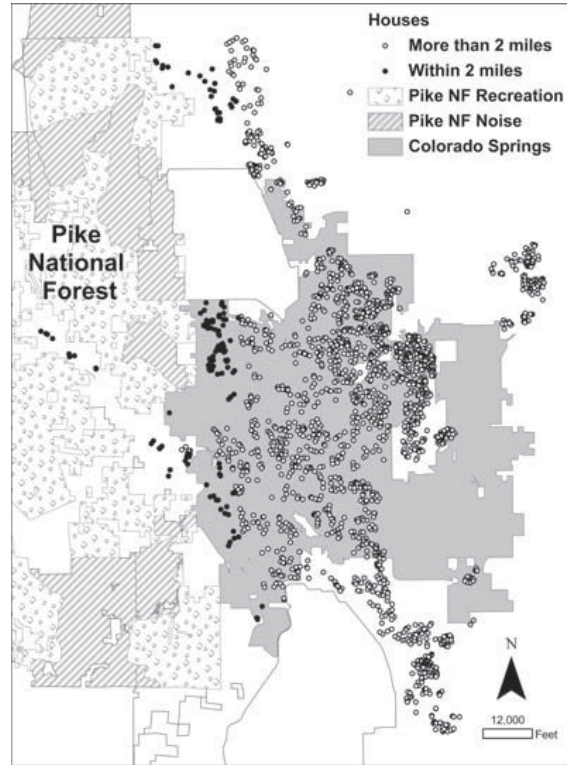


FIGURE 1  
Houses in the Study Area and Land Uses on the Pike National Forest

tains, 70 miles south of Denver. The western portion of the county is extremely mountainous and home to Pikes Peak and the Pike National Forest. El Paso County is approximately 2,158 square miles. The study location is shown in Figure 1 and descriptive statistics are in Table 1. The sample of houses that sold over the time frame of the study is represented such that homes within two miles of noise and recreation on the Pike National Forest have different symbols than the rest of the sample, as defined in the figure legend.

The residential property sales transaction information was obtained from the El Paso County tax assessor. The data included parcel-level information on sale prices, sale dates, and structural characteristics of the property, with spatial coordinates. Market timing variables indicate the year of the sale. Housing structural characteristics include the square footage of the house, lot, basement, and garage, along with the number of bedrooms and

TABLE 1  
Variable Names, Definitions, and Mean Values or Frequencies ( $N = 1,536$ )

Variable	Definition	Mean/Frequency
<i>Sales price</i>	Sale price adjusted to 2005 dollars using Consumer Price Index	\$257,755
<i>House age</i>	House age when sold (year sold less year built)	20
<i>Age_2</i>	House age squared	400
<i>Bathrooms</i>	Number of bathrooms	2.7
<i>Lot area</i>	Total square footage of lot	9,250
<i>House area</i>	Total aboveground square footage of house	1,626
<i>Basement area</i>	Total square footage of finished basement	844
<i>Garage area</i>	Total square footage of garage	457
<i>2006</i>	Dummy variable for sale year (1 if 2006, 0 otherwise)	39%
<i>2007</i>	Dummy variable for sale year (1 if 2007, 0 otherwise)	20.2%
<i>Median income</i>	Median income by census tract	\$61,065
<i>Time to work</i>	Mean time to work by census tract in minutes	24
<i>Pike within 2 miles</i>	Dummy variable for homes within two miles of the Pike National Forest Boundary	6.5%
<i>Pike recreation within 2 miles</i>	Dummy variable for homes within two miles of recreational activities on the Pike National Forest	6.5%
<i>Pike noise within 2 miles</i>	Dummy variable for homes within two miles of noise-intensive activities on the Pike National Forest	3.4%
<i>Pike distance</i>	Distance from house coordinates to nearest boundary for the Pike National Forest in miles	7

bathrooms and the age of the house. However, the number of bedrooms was found to be highly correlated with the house square footage variable, therefore we did not include the number of bedrooms in the final model.

As the decision to purchase a home occurs when the buyer enters the contract approximately two months prior to the ownership change, we subtract 60 days from the sales date and keep transactions from the beginning of March 2005 to end of February 2008 to represent activity within the years of 2005 to 2007. Because homes on more than an acre are potentially developable, we include only homes on one acre or less (Heimlich and Anderson 2001; Lewis, Bohlen, and Wilson 2008). Next, we trimmed the bottom and top 1% of sales to remove outliers and transactions that are not considered arm's-length, such as transactions among family members at less than fair market price. Then, we adjusted the house sales prices using the consumer price index to make comparisons in 2005 dollars.

Neighborhood demographic information was obtained through the U.S. Census web site (U.S. Census Bureau 2000). geographic information system (GIS) shape files available from the web site provide the spatial reference for El Paso County census tracts. Census tract statistics are appended as attributes of the census tracts layer using ArcGIS software. Median income and mean time to work were the two neighborhood variables included in the models from census data because many of the other demographic measures, such as the percentage of students with no high school degree and the percentage nonwhites, are highly correlated with income. Mean time to work was found to be highly correlated with distance to city center, therefore, we selected the mean time to work variable to control for employment opportunities not at city center.

Merging the sales information with census neighborhood demographics and land use layers from the Colorado Ownership and Management Project (COMaP) (Theobald et al. 2008) and El Paso County, we created a geo-

database of spatially referenced attributes for the analysis. COMaP provided the details regarding the specific land uses on the Pike National Forest, while the county's web site<sup>1</sup> was the source for the roads layer and other land use boundaries.

### Amenity Measures for the Pike National Forest

We define national forest proximity through two types of measures: one is continuous Euclidean distance to capture the relative value of location across the landscape, and the other is discrete, within two miles, for adjacency. Similar to Loomis (2004) we created dummy variables for within two miles of the national forest boundary. The two-mile measure captures the visual amenity backdrop of forests and open space. Noise-intensive activities are relatively further from the houses, such that only half of the houses within two miles of the Pike National Forest are also within two miles of noise-intensive activities.

For specifying the heterogeneous land use models, we categorized two types of land uses: noise-intensive activities and recreational activities. We created distance measures to each of the land use types using Euclidean distance in ArcGIS. Noise-intensive activities include motorized vehicle use for recreation and active timber management areas. We expect proximity to noise-intensive activities to decrease house sale prices (Day, Bateman, and Lake 2007). Recreational activities are defined in COMaP as roaded natural and rural recreation areas, and we expect homes with closer access to these to sell for more.

The total number of house sales over the 2005 to 2007 time frame was 31,414 after removing the outliers and homes on more than one acre. To estimate the true values for the parameters with a 95% confidence level the sample size is 1,536. Stratified random sampling was used to create the sample using two strata: (1) homes within two miles of Pike National Forest and (2) homes two miles or more from Pike National Forest. A sample of the

data was also needed to ensure the dataset is computationally feasible for estimation.<sup>2</sup>

## IV. EMPIRICAL MODELS

### Base Hedonic Property Model

The hedonic property model relates the sales price of the house to lot and housing structural characteristics and neighborhood patterns, along with market, location, and environmental variables (Freeman 1993). The empirical specification for Model 1, which treats the national forest lands as homogeneous, is

$$\begin{aligned} \ln P_i = & \alpha_i + \sum_{a=1}^A \beta_a S_{ia} + \sum_{c=1}^C \beta_c N_{ic} + \sum_{d=1}^D \beta_d T_{id} \\ & + \sum_{f=1}^F \rho_f W_{if} P_{if} + \sum_{g=1}^G \lambda_g \varepsilon_{ig} \\ & + \sum \beta_{Pike\ distance} Pike\ distance_i \\ & + \sum \beta_{Pike\ 2\ miles} Pike\ 2\ miles_i + v_i, \end{aligned} \quad [14]$$

where  $\ln P_i$  is the natural log of adjusted house price for observation  $i$ ,  $S_{ia}$  is the  $a$ th structural variable for observation  $i$ ,  $N_{ic}$  is the  $c$ th neighborhood variable for observation  $i$ ,  $T_{id}$  is the  $d$ th timing variable for observation  $i$ ,  $P_{if}$  is the price of the  $f$ th lagged dependent variable,  $W_{if}$  is the  $f$ th spatial weight matrix for observation  $i$ ,  $\varepsilon_{ig}$  is the  $g$ th spatial error for observation  $i$ ,  $\alpha_i$  is the intercept term for observation  $i$ , and  $v_i$  is the i.i.d. error term for observation  $i$ . The variables that represent the location of observation  $i$  with respect to the Pike National Forest are continuous distance, *Pike distance* <sub>$i$</sub> , and a dummy variable for homes within two miles, *Pike 2 miles* <sub>$i$</sub> . The  $\beta$ 's are the estimated coefficients that describe the direction, mag-

<sup>1</sup> El Paso County Colorado assessor GIS maps online, accessed 9/23/2010, [www.elpasoco.com/gis/](http://www.elpasoco.com/gis/).

<sup>2</sup> Spatial subsampling is needed because of computational limits when calculating the log-determinant of the matrix  $(I_n - \rho \mathbf{W})$  to estimate the spatial lag component because  $E(\hat{Y}) = (I - \rho \mathbf{W})^{-1} X \hat{\beta}$ , and  $Cov(\hat{Y}) = \sigma^2 (I - \rho \mathbf{W})^{-1} (I - \rho \mathbf{W})^{n-1}$ .

nitude, and significance for each independent variable.

Variables were selected to represent the economic system while reducing the risk of inflated standard errors of the coefficient estimates from the inclusion of highly correlated variables (Johnston 1984). House structural characteristics included in the model are the living area of the home (*House area*), basement (*Basement area*), garage (*Garage area*), and lot size in square feet (*Lot area*). The age of the house (*Age*) and the age squared (*Age\_2*) are included to determine if nonlinearities exist, and the number of bathrooms are represented as continuous (*Bathrooms*). Neighborhood characteristics by census tract include median income (*Median income*) and mean travel time to work (*Time to work*). Market variables that represent the time of the sale include the annual dummy variables 2006 and 2007, with 2005 as the base case.

Proximity to the Pike National Forest is captured in the variable called *Pike distance*. A negative coefficient indicates houses further from the national forest sell for less. This continuous distance measure is included in both the homogeneous and heterogeneous model specifications to represent the marginal value for a 1% change in mean distance relative to the houses in the rest of the county.

H<sub>0</sub>:  $\beta_{Pike\ distance} = 0$  if no marginal price effect of proximity to the Pike National Forest.

H<sub>a</sub>:  $\beta_{Pike\ distance} < 0$  if house prices are lower further from the Pike National Forest.

### Homogeneous Land Use Specification

To see if there are additional marginal price effects due to adjacency, Model 1 includes a dummy variable to indicate whether the parcel is within two miles of the Pike National Forest (*Pike 2 miles*). The hypothesis test for Model 1 is

H<sub>0</sub>:  $\beta_{Pike\ 2\ miles} = 0$  if there is no marginal price effect from being within two miles of the Pike National Forest.

H<sub>a</sub>:  $\beta_{Pike\ 2\ miles} > 0$  if there is a positive marginal price effect from being within two miles of the Pike National Forest.

### Heterogeneous Land Uses Specification

Model 2 allows for a heterogeneous land use classification by differentiating within two miles of noise-intensive activities (*Pike noise 2 miles*) from those only within two miles of quiet recreational activities (e.g., hiking trail) on the Pike National Forest (*Pike recreation 2 miles*).

$$\ln P_i = \alpha_i + \sum_{a=1}^A \beta_a S_{ia} + \sum_{c=1}^C \beta_c N_{ic} + \sum_{d=1}^D \beta_d T_{id} + \sum_{f=1}^F \rho_f W_{if} P_{if} + \sum_{g=1}^G \lambda_g \varepsilon_{ig} + \sum \beta_{Pike\ distance} Pike\ distance_i + \sum \beta_{Pike\ noise\ 2\ miles} Pike\ noise\ 2\ miles_i + \sum \beta_{Pike\ recreation\ 2\ miles} Pike\ recreation\ 2\ miles_i + v_i \quad [15]$$

We test the following hypotheses to assess whether adjacency to noise-intensive activities has an additional negative marginal effect on home sales prices.

H<sub>0</sub>:  $\beta_{Pike\ noise\ 2\ miles} = 0$  if no marginal price effect from being within two miles of noise-intensive activities on Pike National Forest.

H<sub>a</sub>:  $\beta_{Pike\ noise\ 2\ miles} < 0$  if negative marginal price effect from being within two miles of noise-intensive activities on Pike National Forest.

Likewise, we test whether adjacency to recreational activities has an additional positive marginal effect on home sales prices.

H<sub>0</sub>:  $\beta_{Pike\ recreation\ 2\ miles} = 0$  if no marginal price effect from being within two miles of recreational activities on Pike National Forest.

H<sub>a</sub>:  $\beta_{Pike\ recreation\ 2\ miles} > 0$  if positive marginal price effect from being within two miles of recreational activities on Pike National Forest.

If there are misspecification effects from identifying the Pike National Forest only as a homogeneous land use, the expected relationship among the relative adjacency measures used to calculate implicit prices would be

$$\beta_{Pike\ noise\ 2\ miles} < \beta_{Pike\ 2\ miles} < \beta_{Pike\ recreation\ 2\ miles}$$



TABLE 2  
Regression Results for Joint Spatial Estimation for Model 1

Variable	Parameter Estimate	Standard Error	p-Value	Marginal Price (\$)	95% Confidence Interval (\$) <sup>a</sup>
<i>Constant</i>	5.7426	0.2567	< 0.0001		
<i>House age</i>	-0.0085	0.0006	< 0.0001	-2,191	[-2,494, -1,888]
<i>Age_2</i>	0.0001	< 0.0001	< 0.0001	26	[23, 29]
<i>Bathrooms</i>	0.0153	0.0067	0.0225	3,944	[559, 7,328]
<i>ln(Lot area)</i>	0.1049	0.0118	< 0.0001	3	[2.28, 3.57]
<i>ln(House area)</i>	0.318	0.0187	< 0.0001	50	[45, 56]
<i>Basement area</i>	0.0002	< 0.0001	< 0.0001	52	[47, 56]
<i>Garage area</i>	0.0002	< 0.0001	< 0.0001	52	[36, 67]
<i>2006</i>	0.0884	0.0088	< 0.0001	23,823	[19,008, 28,722]
<i>2007</i>	0.1255	0.0106	< 0.0001	34,466	[28,457, 40,600]
<i>ln(Median income)</i>	0.3053	0.022	< 0.0001	1	[1.11, 1.47]
<i>Time to work</i>	-0.0126	0.0015	< 0.0001	-3,248	[4,006, -2,490]
<i>ln(Pike distance)</i>	-0.0635	0.0115	< 0.0001	-2,243	[-3,039, -1,447]
<i>Pike within 2 miles</i>	-0.0073	0.0269	0.7852		
<i>Rho</i>	-0.0002	0.0005	0.6596		
<i>Lambda</i>	0.2059	0.0259	< 0.0001		
<i>Variance</i>	0.0231	0.0008			

Note:  $N = 1,536$ ,  $IDW = 200$  m,  $PRICE = \$257,755$ ,  $AIC = -2903.76$ , likelihood ratio = 53.95 (< 0.0001). Lagrange multiplier = 0.2409 (0.6236), Moran's  $I = 0.018$  (0.6119), residual standard error = 0.1526.

<sup>a</sup> Confidence intervals for coefficient estimates are calculated using the mean  $\pm 1.96$  times the standard error.

Thus, the marginal value of adjacency to noise-intensive activities is expected to be less than the marginal value of proximity to the Pike National Forest in general. The marginal value of adjacency to recreation is expected to be greater than both the marginal value of adjacency to noise-intensive activities and adjacency to the Pike National Forest in general.

## V. RESULTS

### Spatial Dependence

We found evidence of spatial dependence. The joint spatial lag and spatial error models achieved the smallest AIC relative to the other models that represent only the spatial lag or the spatial error components. Across all spatial weight matrices considered (100, 160, 200, and 400 m),<sup>3</sup> Moran's  $I$  and the Lagrange multiplier test statistics are found to be highly significant when the spatial lag and error components are included separately, indicating there remains spatial dependence unexplained and thus the need for the joint specification.

<sup>3</sup> Results from models estimated using alternative spatial weight matrices are available in the dissertation by Charlotte Ham (2011).

The semivariogram of the residuals from the OLS models indicates nearer neighbors have more influence than those further away, and the effect levels off around 200 m. Therefore, the joint spatial lag and error specification using an inverse distance weight matrix to 200 m accounts for spatial dependence among neighbors.

### Housing, Neighborhood, and Market Variables

The coefficients on the housing and neighborhood variables have the expected signs and are consistent across the two models (Tables 2 and 3). The direction, magnitude, and significance of the housing structural variables are as expected such that house prices increase with an increase in lot, house, garage, and basement area. The lot and housing marginal implicit prices are similar to those found in the study by Donovan, Champ, and Butry (2007), which also used an El Paso County sample. House prices decrease as they age, and the rate is higher for newer homes than older ones. House prices increase with the number of bathrooms. For neighborhood characteristics by census tract, median house-

TABLE 3  
Regression Results for Joint Spatial Estimation for Model 2

Variable	Parameter Estimate	Standard Error	p-Value	Marginal Price (\$)	95% Confidence Interval (\$) <sup>a</sup>
Constant	5.7666	0.2563	< 0.0001		
House age	-0.0085	0.0006	< 0.0001	-2,191	[-2,494, -1,888]
Age_2	0.0001	< 0.0001	< 0.0001	26	[23, 29]
Bathrooms	0.0152	0.0067	0.0229	3,918	[533, 7,303]
ln(Lot area)	0.1049	0.0118	< 0.0001	3	[2.3, 3.6]
ln(House area)	0.3177	0.0187	< 0.0001	50	[45, 56]
Basement area	0.0002	< 0.0001	< 0.0001	52	[47, 56]
Garage area	0.0002	< 0.0001	< 0.0001	52	[36, 67]
2006	0.0887	0.0088	< 0.0001	23,907	[19,091, 28,808]
2007	0.1263	0.0106	< 0.0001	34,700	[28,686, 40,839]
ln(Median income)	0.3076	0.022	< 0.0001	1	[1.12, 1.48]
Time to work	-0.0129	0.0015	< 0.0001	-3,325	[4,083, -2,567]
ln(Pike distance)	-0.0654	0.0115	< 0.0001	-2,310	[-3,106, -1,514]
Pike within 2 miles	-0.0711	0.0342	0.038	-17,690	[-33,255, -1,046]
Pike recreation within 2 miles	0.0255	0.0312	0.4126		
Rho	-0.0002	0.0005	0.6316		
Lambda	0.2019	0.0259	< 0.0001		
Variance	0.023	0.0008			

Note:  $N = 1,536$ ,  $IDW = 200$  m,  $PRICE = \$257,755$ ,  $AIC = -2,906.04$ , likelihood ratio = 51.65 ( $< 0.0001$ ). Lagrange multiplier = 0.2444 (0.6211), Moran's  $I = 0.018$  (0.6094), residual standard error = 0.1525.

<sup>a</sup> Confidence intervals for coefficient estimates are calculated using the mean  $\pm 1.96$  times the standard error.

hold income is positively related to house prices and house prices decrease as the mean travel time to work increases. For market variables, houses sold in 2006 and 2007 sell for a premium relative to those sold in 2005.

### Pike National Forest Proximity Measures

A 1% decrease in mean distance to the Pike National Forest increases house prices by 6.4% (95% confidence interval is 4.1% to 8.6%, Table 2) in the homogeneous model and by 6.5% (4.3% to 8.8%, Table 3) in the heterogeneous model, indicating people value living closer to the Pike National Forest. The positive and significant contribution of national forest land was also found in the studies by Cho et al. (2009) and Hand et al. (2008). In addition to the value across the landscape, the adjacency measure in the homogeneous model that represents homes within two miles of the Pike National Forest is not statistically significant ( $p$ -value = 0.7862), indicating there is no additional price premium other than that represented in the continuous distance measure. However, the adjacency measures in the heterogeneous model indicate being within two

miles of noise-intensive activities decreases house sales prices by 6.9% (0.4% to 13.8%) or evaluated at the mean  $-\$17,690$  ( $-\$1,046$  to  $-\$33,255$ ) ( $p$ -value = 0.038).<sup>4</sup> Adjacency to recreation does not exhibit an additional premium over that captured in the continuous distance measure. In terms of our hypothesis tests only  $\beta_{Pike\ distance} < 0$  and  $\beta_{Pike\ noise\ 2\ miles} < 0$ , indicating there is a price premium for living closer to the Pike National Forest but homes closer to noise-intensive activities sell for less.

Thus, to test the usual hypothesis that house prices near a national forest would be higher requires more than just examining houses within a given distance of the nearest national forest boundary. It is important to know what and where different land management activities are occurring relative to houses. Some of these activities may be undesirable (timber harvesting) and some may be desirable (hiking trails). Treating the entire national forest as one undifferentiated land use can lead to an erroneous estimate of the

<sup>4</sup> Results from models estimated using multiple distance cutoffs are available in the dissertation by Charlotte Ham (2011).

implicit price of the national forest when there are disparate activities.

## VI. CONCLUSION

This paper investigates the importance of accounting for heterogeneity of land uses on a national forest using data on single-family housing sales transactions around the Pike National Forest in Colorado from 2005 to 2007. In particular, we examined the direction and magnitude of the price effects for being closer to the Pike National Forest depending on the land uses in the areas nearest homes. To learn more about the value of adjacency to the Pike National Forest, we examined two separate models: one that designates houses within two miles of the Pike National Forest in general, and the other according to the characteristics of specific land uses occurring near the federal land boundary, including recreation or noise-intensive activities. The results of this study suggest that in some cases hedonic price analyses should take into consideration how the actors in a market consider the good of interest. In this case, home buyers near the Pike National Forest appear to discount living close to noisy activities on a national forest. This recognition in our analysis allows us to provide managers at the Pike National Forest with better information about how people value the benefits (or costs) associated with the different land uses for incorporation in land management planning.

We also found that the amenity values for houses near the Pike National Forest are positive and significant across models when considering houses throughout the entire county. However, disaggregating the Pike National Forest by use rather than assuming the forest is homogeneous provides a clearer picture of the values home buyers place on actual land uses. In particular, treating the Pike National Forest as a homogenous land type overstates the benefits for houses located within two miles of noisy land uses. Thus, treatment of the national forest as one homogeneous land use by owner or manager is a misspecification and can have misleading policy implications. Future research can address whether these land use effects are observed on other national forests and public lands.

## Acknowledgments

The authors would like to gratefully acknowledge the helpful advice and comments of participants at the Environmental and Resource Economics Workshop in Vail, Colorado, 2008; participants at the USDA W2133 Annual Meeting, Austin, Texas, 2009; along with David Butry, Scott Baggett, and the anonymous referees for *Land Economics*. We appreciate the assistance of the El Paso County assessor's office and the area federal land agency contacts for the data and verification. The research was funded through a partnership between the USDA Forest Service Rocky Mountain Research Station and the Center for Environmental Management of Military Lands at Colorado State University.

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