GIS-Based Estimation of Housing Amenities:

The Case of High Grounds and Stagnant Streams

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Abstract: We use GIS and econometric methods to estimate the marginal implicit values of environmental amenities associated with residential land parcels in the mountain town of Logan, Utah. Amenities include proximity to open spaces (such as parks, golf courses and lakes), commercial zones, major roads, streams, and general visibility of surrounding topography in the valley as determined by the elevation of the land parcel. The amenity value estimates are corrected for spatial autocorrelation. We find a positive relationship between a parcel's value and its elevation, and a negative relationship between value and adjacency to a stagnant stream. To our knowledge, this is the first hedonic study to assess the effect of stream stagnancy on land value.

Keywords: hedonic valuation; stagnant streams; high elevation

JEL Classification: Q51, Q59

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1. Introduction

With the recent downturn in the US home market, prospective homebuyers have become more attentive to implicit values associated with the amenities of a given house (Little, 2010 and Boyce, 2010). In concert with the economic downturn and homebuyers' heightened attentiveness, local governments now have greater incentive to better understand the determinants of land values, for both property-tax and community-planning purposes. Mountain towns in particular have two amenity values that are not commonly estimated in hedonic valuation studies and thus not well understood by local policy makers – visibility of the valley (as determined by elevation of the land parcel) and proximity to running and stagnant streams. This paper fills this gap in the literature by using Geographic Information System (GIS) data for the mountain town of Logan, Utah, and employing recently developed econometric methods to control for spatial autocorrelation in the estimation of marginal implicit amenity values. We find a positive relationship between a land parcel's value and its elevation, and a negative relationship between value and adjacency to a stagnant stream. To our knowledge, this is the first hedonic study to assess the effect of stream stagnancy on land value.

Rosen (1974) initially interpreted housing as differentiated products embodying varied characteristics. According to Rosen, these characteristics are not explicitly traded in markets, however their implicit marginal values can nevertheless be "revealed" through hedonic analysis. Rosen's (1974) method of estimating the hedonic equation through demand and supply interaction was later criticized by several authors, such as Bartik (1987) and Palmquist (1984), which in turn spawned interest in measuring the effects of different spatial arrangements. More recently, hedonic studies have incorporated GIS data to account for the viewshed characteristics of housing units (Benson et al., 1998 and Paterson et al., 2002).

Using GIS applications to analyze spatial information, such as land records, natural resource features, and public infrastructure location has become popular in the hedonic literature (Geoghegan, et al., 1997). For example, Cavailhes et al. (2009) evaluate hedonic landscape prices in the urban fringe of Dijon, France. The authors' viewshed analysis quantifies the fringe's visibility zone, enabling an explanation of how landscape features affect housing prices. They find that an obstruction of 10% of the viewshed (primarily of fields and trees) entails a loss in housing value of as much as € 2000 or more (approximately 2% of the average house price).

Irwin (2002) estimates the marginal values of different open space attributes using residential sales data from central Maryland in the US. The author reports marginal benefits of preserving open space ranging from $994 to $3,307 per acre of farmland per household, depending upon whether the land parcel is publicly or privately owned. However, Irwin's (2002) results do not control for spatial autocorrelation in the data. In contrast, Sengupta et al.'s (2003) estimation of ranchette prices in Montana uses an inverse squared distance weights matrix to correct for spatial autocorrelation. The authors find that spatial autocorrelation exists in the data. Correcting for autocorrelation, Sengupta et al. (2003) find that per-acre value of ranchettes increases by approximately $1,400 for a one-percent improvement in a satellite greenness index. They also report that increased distance from a major road decreases per-acre ranchette value by more than one dollar per mile.

In conjunction with this literature, this paper uses assessed values of land parcels and a host of GIS-derived explanatory variables to estimate the marginal implicit values of a variety of housing amenities. Explanatory variables include distance of the residential land parcel to nearest major road, distance to nearest commercial units (which include shopping malls, groceries, and other businesses), distance to nearest recreational area (which includes parks, lakes, and golf courses), year in which a house was built on the land parcel (which proxies for age of the parcel's development), neighborhood median household income, neighborhood population density, elevation of the land parcel, and the parcel's proximity to the nearest stagnant stream.

To our knowledge, the effect of stagnant stream proximity on a land parcel's value is novel to the hedonic literature. In our dataset, streams are distinguished by slope, and slopes vary considerably in our study area. The main river flowing through Logan is a tributary of the Little Bear River. This river supplies irrigation water through a system of canals, which are more or less stagnant. Residential land parcels located close to these canals are therefore commonly affected by bugs and excessive foliage, in addition to any potential positive attributes associated with stream access. Since Logan is a mountain town, a land parcel's elevation also potentially determines value based upon social prestige and perceived safety during floods. Higher parcels also provide better visibility of the valley. Again, we find a positive relationship between a land parcel's value and its elevation, and a negative relationship between value and adjacency to a stagnant stream.

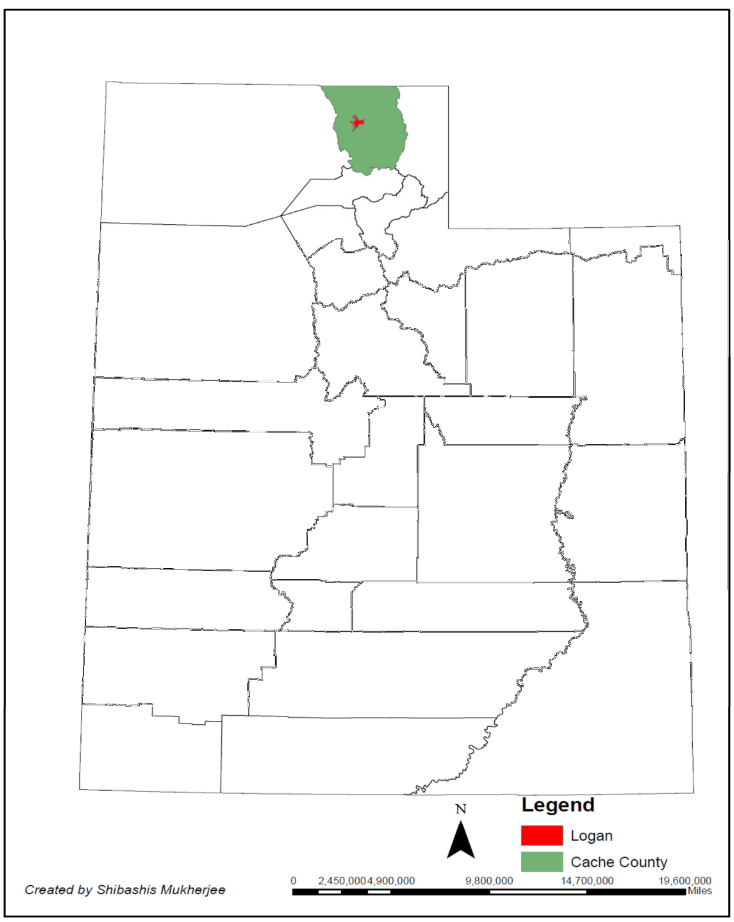
The remainder of the paper is organized as follows. Section 2 briefly describes the geography and demography of Logan, focusing on the housing sector. Section 3 presents the underlying hedonic theory adopted in this study. Section 4 describes the data and

Section 5 develops the empirical model used to estimate the data. Section 6 presents our empirical findings, and Section 7 concludes.

2. Description of study area

Logan is the main city in Cache County, located in northern Utah at an elevation of 4534 feet above mean sea level (USGS, 2008) and covering approximately 17 square miles in area (see Figure 1). Mormon Pioneers settled in Logan in 1859 and incorporated the settlement in 1866 (Simmonds, 1976). From 1990 to 2000 the city's population increased by 30.2%. It is expected that Logan's population will triple in size within the next 50 years, from its current size of 53,000 to 150,000 people (USCB, 2009).

Figure 1. Map of Logan's Location in Utah.



During the period 2000-2003 Cache County, Utah was ranked 12th among US counties in births per 1000 people, and ranked 49th lowest in number of deaths per 1000 (Utah Governor's Office, 2009). According to the Utah Health Department (2008), the state's average age of marriage for women is 22 years, and that for men is 24 years, both of which are among the lowest in the US. More than 40% of the city's population is between the ages of 20 – 34 years. Due to early marriages, the average age of couples buying homes is therefore relatively low.

3. Hedonic Valuation Model

We extend Paterson and Boyle's (2002) theoretical framework by specifying both the demand and supply sides of an underlying hedonic-pricing function.[1] Letting x represent the numeraire good (e.g., a composite commodity representing all goods other than housing), **E** represent a vector of environmental characteristics from which households derive amenity value, **L** represent lot characteristics (e.g., year built, acreage, and elevation), and **N** represent a vector of neighborhood characteristics (e.g., population density), a household's utility can be specified as,

$$U = U(x, \mathbf{\Omega}) \tag{1}$$

where $\mathbf{\Omega}$ represents the set containing vectors **E**, **L,** and **N**.

The household's problem is to maximize (1) subject to its budget constraint,

$$I = x + V(\mathbf{\Omega}) \tag{2}$$

where I represents household income and V represents the land parcel's assessed value, which is directly dependent upon the elements of $\mathbf{\Omega}$. In addition, a potential seller's profit from offering a land parcel for sale can be thought of as:

[1] See Rosen (1974) and Palmquist (1991) for more detailed theoretical frameworks.

$$V(\mathbf{\Omega}) - \mathrm{C}(\mathbf{\Omega}) \qquad (3)$$

where C represents a standard cost function defined over $\mathbf{\Omega}$. In a market equilibrium, for any given attribute included in $\mathbf{\Omega}$, denoted q, a household chooses a parcel such that its marginal valuation of that q (i.e., the household's implicit value for q) equals a seller's marginal valuation of the same q (i.e., the seller's implicit value for q).[2] In other words,

$$\frac{\partial V}{\partial q} = \frac{\partial U / \partial q}{\partial U / \partial x} = \frac{\partial C}{\partial q} \qquad (4)$$

Our objective in this study is to estimate a vector of regression coefficients ($\boldsymbol{\beta}$s), which are akin to the marginal implicit values represented by $\frac{\partial V}{\partial q}\left(= \frac{\partial C}{\partial q}\right)$ in (4) for each q.

4. Data

The data used in this analysis is a cross-section from the year 2006. The sample of Logan residential land parcels was drawn from a GIS database provided by the Cache County Development Services Office in Logan, Utah. The database contains assessed tax values for a population of over 46,000 parcels located in the county, including separate tax values for land and buildings. It also includes acreage, year home was built, and tax ID number. Prior to estimation, invalid and inappropriate records were omitted (these included lots with zero acreage, negative land assessed values, etc.). A zoning map (which categorizes the parcels into agricultural, commercial, industrial, manufactured homes, public, recreational, residential, and residential overlay) was used to filter out

[2] Since we are using tax assessor data, rather than actual market data, the hedonic valuation model essentially approximates the equilibrium that our data would reflect if it were in fact market data.

Logan's residential land parcels. After accounting for these restrictions and deletions, the final database contained observations on a population of roughly 9,000 parcels.

A GIS shapefile of major roads, streams, and recreational zones was obtained from the website of Utah GIS Portal (http://gis.utah.gov/sgid) on January 05, 2010. Data on population density and median household income was obtained from the U.S. Census Bureau (2010). Topographical data were taken from the digital elevation model (DEM), constructed by the U.S. Geological Survey from 7.5 minute (1 : 24,000 scale) quadrangles with ten-foot contour intervals. This data was converted to the projection North American Datum 1983, Universal Transverse Mercator – zone 12 north. The polygon shapefiles of parcels were converted into point shapefiles to calculate proximity measures such as distance to nearest major road, stream, commercial unit, and recreational zone.

The remaining explanatory variables – parcel elevation and stream slope – were generated using ArcGIS software. Distance to stream was ultimately defined as a dummy variable, where adjacent parcels receive a value equal to 1, and 0 otherwise. Since we are interested in observing the effect of stream stagnancy on land value, we consider the adjacency of residential land parcels to streams with slopes of one degree or less, where the dimensions are in meters. A stream with slope one degree or less (i.e., a fall of at most 0.0174 meters per meter) is considered stagnant according to Paustian (1992) and Maser (2010). The latitudinal-longitudinal information for each parcel was added to the original dataset using a DEM of Cache County, which was also available on the Utah GIS portal.

Table 1 describes each variable used in our ensuing regression analysis, along with its sample mean and standard deviation.[3]

Table 1. Dependent and Explanatory Variables: Definitions and Descriptive Statistics.

Variable	Description	Mean	Standard Deviation
lvalacln	Natural log of assessed per acre land value (dollars).	9.99	0.50
roadln	Natural log of distance of parcel to nearest major road (miles).	6.28	0.614
dsl1	Adjacency to stream with slope one degree or less,= 1 if adjacent, 0 otherwise.	0.29	0.46
comln	Natural log of distance of parcel to nearest commercial zone (miles).	5.97	0.96
builtln	Natural log of year in which residential land parcel was built (1862 =1, 1863 = 2, etc.).	4.62	0.36
eleln	Natural log of elevation of parcel (feet above mean sea level).	4.73	0.84
recln	Natural log of distance of parcel to nearest recreational zone (miles).	7.24	0.03
denln	Natural log of neighborhood population density (persons per square mile).	10.53	0.33
incln	Natural log of neighborhood median household income (dollars).	4.60	0.37

[3] As discussed further in Section 6 (see footnote 6), computational limitations restricted us to taking a random sample of 1700 observations from the population of 9000. The means and standard deviations reported in Table 1 are therefore based upon this random sample.

5. Empirical Model

Overall, a double-log specification fit our data best.[4] Thus, our general estimation equation is specified as,

$$\ln V = \alpha_0 + (\ln \boldsymbol{\Omega})' \boldsymbol{\beta} + e \tag{5}$$

where, α_0 is a constant term, $\boldsymbol{\beta}$ is a corresponding vector of coefficients for attributes included $\boldsymbol{\Omega}$ (which are drawn from Table 1 for this study), and e represents an error term (independent and identically distributed with mean zero and constant variance σ^2 after correcting for spatial autocorrelation). As is well known, in the double-log specification the $\boldsymbol{\beta}$ coefficients provide mean estimates of elasticity.

The most common problem with spatial data is spatial dependency, or spatial autocorrelation. This problem is similar to that for serial autocorrelation in time series data. Spatial autocorrelation implies a covariation of properties within geographic space: characteristics at proximal locations are correlated with one another, either positively or negatively. There are three possible explanations for this.

One explanation is a simple spatial relationship: latent determinants of an observation in one location also determine similar observations in nearby locations. A second possibility is spatial causality: something at a given location directly influences the characteristics of nearby locations. A third possibility is spatial interaction: the movement of people, goods or information creates apparent relationships between locations (Bhatta, 2010). The standard assumption of independence of observations is violated due to the existence of spatial autocorrelation. This problem can lead to unreliable coefficient estimates.

[4] Box-Cox transformation analysis (using the ‘boxcox’ command in Stata SE v. 11.1) indicates that a double-log specification is statistically justified. Dummy variables are not logged in our double-log models.

In our case, various spatiality tests (generated by the 'spatdiag' command in Stata) indicated the presence of spatial autocorrelation in the data.[5] To correct for spatial dependence we used the 'spatwmat' command (Pisati, 2001). This command generates a spatial weights matrix (where each element of the spatial weights matrix, w_{ij}, is defined as the inverse distance between observations *i* and *j*) as well as an eigenvalue matrix, which is used by the 'spatreg' command to generate spatially corrected estimates.

The spatreg command offers two different modeling approaches to control for spatial autocorrelation – a lag model and an error model. The spatial lag model introduces an additional regressor to the basic model (5) in the form of a spatially dependent variable, which in our case is the inverse distance matrix. This model is appropriate when the focus is on the assessment of existence and strength of spatial interaction. On the other hand, the spatial error model addresses spatial dependence in the regression disturbance term directly. It is a special case of a regression with a non-spherical error term, in which the off-diagonal elements of the covariance matrix express the structure of spatial dependence (Anselin, 1999). For simplicity, we estimate a lag model using the inverse distance matrix.

Following Anselin (1988), a general model of housing valuation including spatial effects can be expressed as,

$$\begin{aligned} &V = \rho W_1 V + \boldsymbol{\Omega}'\boldsymbol{\beta} + \varepsilon \\ &\varepsilon = \lambda W_2 \varepsilon + \mu \\ &\mu \sim N(0, \sigma^2 I) \end{aligned} \tag{6}$$

where W_1 and W_2 are NxN spatial weights matrices. We have used inverse distance between parcels as spatial weights for our study. Vector ε is an Nx1 spatial autoregressive

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[5] We used Stata SE v. 11.1 on a Mac operating system with 16 gigabytes of memory to perform our analysis.

error term, μ is an Nx1 normally distributed random error term with mean zero and constant variance σ^2, and ρ and λ are coefficients on spatially lagged variables V and ε.

According to Taylor (2003), estimation of models with spatial dependence, but not spatial heterogeneity (i.e., λ=0 in equation (6)), are less computationally intensive. Gawande et al. (2001) also point out that estimation of λ via maximum likelihood becomes problematic with large samples sizes. Therefore, we assume λ=0 and the hedonic valuation model with spatial effects in our case becomes,

$$\begin{aligned} \ln V &= \rho W_1 \ln V + \mathbf{\Omega}'\boldsymbol{\beta} + \varepsilon \\ \varepsilon &\sim N(0, \sigma^2 I). \end{aligned} \tag{7}$$

Equation (7) is the equation we ultimately estimate in Section 6.

6. Empirical Results

As mentioned in Section 5, the double-log specification of our model fit the data sufficiently well. We therefore began by estimating an OLS version of the double-log model to establish a basis for comparison. In columns two and three of Table 2, we report the coefficient estimates and associated standard errors, respectively, from an OLS model (corrected for heteroscedasticity using White's (1980) method) using a random sample of 1700 observations.[6] We find that several of our coefficients are statistically significant in explaining variation in assessed land value.[7] In particular, median household income

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[6] Computational limitations confined us to randomly sampling 1700 observations from our population of approximately 9000. We performed our analysis on a Mac operating system with 16 gigabytes of memory. Access to this workstation was provided by the High Performance Computing facility at Utah State University. Using the 'spatwmat' command (discussed above), the workstation was able to handle a maximum of 1700 observations. Computational limitations also constrained us from bootstrapping the standard errors; nevertheless random sampling of 1700 observations satisfies large-sample properties.

[7] We ran several specifications of (7) using different combinations of the explanatory variables contained in Table 1. In the end, the variables *builtln, recln,* and *denln* were excluded from the analysis due to their relatively high correlations with the remaining variables. Results for our excluded analyses with these variables included are available upon request from the authors.

(*incln*) and distance to the nearest commercial zone (*comln*) are positively related with land value, while adjacency to a stagnant stream (*dsl1*) is negatively related. These results are interpreted below.

Table 2. Estimation Results (*lvalacln* dependent variable).

Explanatory Variables	**OLS Model**		**Spatial Autocorrelation Model**	
	Coefficient	Standard Error	Coefficient	Standard Error
Constant	8.65***	0.247	10.17***	0.291
Roadln	-0.024	0.020	-0.063***	0.021
dsl1	-0.104***	0.026	-0.081***	0.026
Comln	0.044***	0.012	0.028**	0.012
Eleln	0.021	0.017	0.079***	0.017
Incln	0.251***	0.031	0.118***	0.036
P	-	-	-0.083***	0.008
Summary Statistics				
N	1700		1700	
Adj. R^2	0.05		.	
F	23.22***		.	
Moran's I	63.92***		.	
Log Likelihood	.		-1142.12	
χ^2 (Wald Test)	.		96.88***	

***significant at 1% level, ** significant at 5% level, *significant at 10% level

Since the estimated Moran's I index (Moran, 1948) for the OLS regression reported in Table 2 of 63.92 is statistically significant at the 1% level, uncontrolled spatial autocorrelation in the data is affecting the OLS results (spatial autocorrelation is also indicated by the statistical significance of the estimated ρ parameter in the spatial autocorrelation model represented by (7)). Results for the spatial autocorrelation model (described in Section 5) are presented in columns four and five of Table 2.

As in the OLS model, the coefficient estimates for *incln* and *comln* are both positive and statistically significant (the significance level drops to 5% for *comln*). In particular, one-percent increases in the value of each variable on average, and all else equal, result in roughly 0.12 and 0.03 percent increases, respectively, in residential land value. The positive relationship between *comln* and *lvalacln* indicates that on average households in Logan are willing to tradeoff the inconvenience of being located farther from a commercial zone for reduced congestion effects and any gains in amenity value that such distance provides. Similarly, *dsl1* is negatively related to land value. In particular, the value of a parcel located adjacent to a stagnant stream is 0.08 percent less than an identical non-adjacent parcel, all else equal. In other words, on average any advantages associated with living adjacent to a stream of at most 1 percent slope are offset by its disadvantages.

Unlike the OLS model, the coefficient estimate for *roadln* is negative and statistically significant at the 1% level. Concomitant with the positive coefficient estimate for *comln*, this result suggests that while Logan households value locating farther from commercial zones, they do not value the attendant distance from major roads. One possible explanation for this statistical paradox is that commercial hubs are generally located alongside major roads. Logan households therefore see nearby major roads as enabling quick access to commercial zones, yet at the same time providing distance between their homes and congestion in the zones themselves.

The coefficient estimate for *eleln* is now positive and statistically significant, as expected. In particular, a one percent increase in elevation increases a parcel's value by 0.08 percent, all else equal. In other words, Logan households prefer living at higher elevations, where there is generally less congestion and better views of the valley. This result is consistent with the previous literature (Benson et al., 1998 and Sander et al., 2009).[8] Finally, the Wald test indicates that the overall fit of the model is statistically significant at the 1% level.

7. Conclusions

We have used GIS data and econometric methods that control for spatial autocorrelation in the data to estimate the marginal implicit values of environmental amenities associated with residential land parcels in the mountain town of Logan, Utah. Amenities include proximity to open spaces (such as parks, golf courses and lakes), commercial zones, major roads, streams, and general visibility of surrounding topography in the valley as determined by the elevation of the land parcel. Most pertinent for this study, we have found a positive statistical relationship between a parcel's value and its elevation, and a negative relationship between value and adjacency to stagnant streams. Although hedonic analysis of environmental attributes has become increasingly prevalent in the economic literature, mountain towns such as Logan, Utah have not been studied as often. To our knowledge, classification of streams based on slope is a novel approach to controlling for stream adjacency in mountainous areas.

[8] Garrod et al. (1992) and Paterson et al. (2002) find that elevation can have a negative effect on land value when the parcels are associated with specific disamenities.

For states such as Utah, which have implemented non-disclosure policies, assessed land values are a convenient source of real estate data, but do not provide as accurate a measure of value as market sales prices themselves. Future work should therefore work to incorporate market transaction values obtained from local real estate agents. Nevertheless, an approximate implicit value of housing amenities can be identified using assessed valuation, as has been done in this study. Our results can help real estate developers and local planners price undeveloped areas with similar amenities. The study's results can also reduce the cost of obtaining estimated assessed values. Our empirical approach can also be used to help cities estimate the effect on their tax bases of various land improvements.

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