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ANALYSIS

Environmental amenities and agricultural land values: a hedonic model using geographic information systems data

Chris T. Bastian, Donald M. McLeod *, Matthew J. Germino, William A. Reiners, Benedict J. Blasko [1]

Department of Agricultural and Applied Economics, University of Wyoming, P.O. Box 3354, Laramie, WY 82071-3354, USA

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Abstract

Remote agricultural lands, which include wildlife habitat, angling opportunities and scenic vistas, command higher prices per hectare in Wyoming than those whose landscape is dominated by agricultural production. Geographic information systems (GIS) data are used to measure recreational and scenic amenities associated with rural land. A hedonic price model is specified with GIS measures. It is used to estimate the impact of amenity and agricultural production land characteristics on price per acre for a sample of Wyoming agricultural parcels. Results indicate that the specification performed well across several functional forms. The sampled land prices are explained by the level of both environmental amenities as well as production attributes. Statistically significant amenity variables included scenic view, elk habitat, sport fishery productivity and distance to town. This analysis permits a better estimation of environmental amenity values from hedonic techniques. Improved estimation of amenity values is vital for policies aimed at open space preservation, using agricultural conservation easements and land use conflict resolution.

Keywords: Environmental amenities; Geographic information systems data; Hedonic; Rural; Agriculture; Land values

1. Introduction

Agricultural land values can be estimated by summing the discounted productive rents (for a useful summary see Robison et al., 1985). This approach may reflect soil quality, capital improvements, water supply and location to markets. Agricultural land provides land for current and future development, recreation, access to public lands, wildlife habitat, and open space. Land,

* Corresponding author. Tel.: +1-307-766-3116; fax: +1-307-766-5544.

E-mail address: dmcleod@uwyo.edu (D.M. McLeod).

[1] Senior Authorship is shared by the first two authors. Authors are agricultural marketing specialist and assistant professor from the Department of Agricultural and Applied Economics, University of Wyoming, Laramie, WY; PhD at Land Resources Department, Montana State University, Bozeman, MT; professor and former research assistant from the Department of Botany, from the University of Wyoming, Laramie, WY.

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following Xu et al. (1993), can be viewed as an input to production; space for amenities (provision of public goods via place); fixed and taxable (provision of public goods via net revenue); and as an asset (capital good). Sale price should be the outcome of the total market value of a parcel, given existing and efficient markets.

The demand for productive capacity by agriculturalists drives in part the demand for agricultural land. Rural land prices may also reflect households' demand for homes with rural amenities. Rural amenities in the Rocky Mountain region include abundant public lands, recreational opportunities, wildlife, and open spaces.

Agricultural land is being converted into non-agricultural uses across the US (Vesterby et al., 1994) and the Rocky Mountain region. Rocky Mountain counties containing or bordering national forest wilderness areas experienced population gains from 1970 to 1985 (Rudzitis and Johansen, 1989). Population in western states grew by 16.7% from 1990 through 2000 (Center of the American West, n.d.). Population in Utah, Idaho and Colorado grew by 29.6, 28.5, and 30.6%, respectively, in that period (Taylor, n.d.). Population in western Wyoming counties grew by 10–63% during the same period with Teton county experiencing the highest growth at 63.3% (Taylor, n.d.). The population in the rural (unincorporated) areas accounted for 55.2% of the population growth in Wyoming (Taylor, n.d.).

Growth affects agricultural land in terms of aggregate producer output and income. It can have an impact on production practices via nuisance regulations or land use laws. Growth also may affect the viability of input suppliers.

Public goods associated with agricultural land (wildlife, scenery, open space), and the economic as well as fiscal base of rural counties, may be affected by growth as well. Rural residential development is a leading cause of rural land fragmentation. Fragmentation of forests, rangeland and watersheds impacts wildlife habitat, water quality, recreation opportunities, and viewsheds.

These potential impacts of growth, and the diversity of benefits associated with agricultural lands, suggest that agricultural land may be demanded in various input markets by competing market segments. It is important for landowners, land demanders and land policy analysts to recognize what factors drive land prices. These factors may increase the number of rent generating activities on a given agricultural parcel, thereby improving the viability of a given operation. Such knowledge may provide insight into land characteristics that prompt the conversion of agricultural land to other uses (identification of open space and wildlife habitat at risk of being developed). Insights given in this paper may lead to differential property taxation approaches and improved valuation and appraisal processes as they relate to land use policies. Geographic information systems (GIS) permit a quantitative means of affixing land characteristics to their location. This paper demonstrates how GIS data can be used to assess marketable attributes of agricultural lands in Wyoming.

Specifically, our research objectives are as follows:

1. Estimate a hedonic model with land price as a function of productive and amenity attributes.
2. Incorporate parcel-specific GIS derived measures of amenities in the model.

2. Theory of hedonic price valuation

The hedonic technique is based on the premise that goods traded in the market are made up of different bundles of attributes or characteristics. Hedonic price models (HPM), including GIS delineated variables, permit inferring the impact of land attributes on land values.

Benefits of a change in valued land attributes may be measured from the underlying demand for the characteristic, or characteristics, of interest HPM are based on a differentiated product ($\mathbf{Z}_i$) that can be represented by a vector of product (land) attributes (see Rosen, 1974; Bartik, 1987; Palmquist, 1991). The $\mathbf{Z}_i$ vector for this analysis is based on two sets of characteristics, agricultural production attributes, z_{ag}, and amenities attributes, z_{am}. These characteristics are thought to appeal to two rural land market segments: agricultural producers and demanders of rural residences. The observed price for $\mathbf{Z}_i$ in the market is defined as a hedonic function of its characteristics represented by

$$P(\mathbf{Z}i) = P(z_{\mathrm{ag}1},\ldots,z_{\mathrm{ag}n},z_{\mathrm{ag}1},\ldots,z_{\mathrm{am}n}). \quad (1)$$

The marginal impact on-parcel price, $P(\mathbf{Z}_i)$, of any z_i can be estimated from this function (1).

Equation 1 is a reduced form model indicating the attributes of a parcel relevant to both buyers and sellers of agricultural land. The demand for/supply of agricultural land can be considered as a factor demand/supply model associated with a production function including agricultural outputs, with non-agricultural rent generating opportunities and with a demand function for residential sites. Economic theory does not provide much direction concerning the functional form of the HPM. Several functional forms are examined in this study. Model evaluation is based on overall goodness-of-fit and, more importantly, hypothesis testing for attributes affecting parcel price.

3. Study area

Wyoming can be considered as a large, rural and heterogeneous land market. It consists of irrigated basins and forested range in the west as well as desert and high plains in the central and eastern part of the state. The state is divided into two regions for this analysis. The regions roughly follow the Bureau of Land Management (BLM) Ecoregions as reported in USDA/USDI (1993). Region 1 (BLM Ecoregion 7 and 8, south part) includes counties in the western part of the state. These counties are directly south and east of Yellowstone and Teton National Parks. The Snake, Bighorn, and Green River basins, known for their blue ribbon trout fisheries, are located in these counties. Region 2 (BLM Ecoregion 8, central part and Ecoregions 4 and 5) covers the central and eastern part of Wyoming. Federal lands are found in both regions. US Forest Service lands dominate in Region 1 with BLM as the major federal land agency elsewhere.

Wyoming agriculture primarily consists of livestock and forage production followed by grain, dry bean and sugar beet production. Region 2 has the most crop acres. It has the highest value crop and livestock operations compared to the remainder of the state. It is the dominant agricultural region of the two as measured by agricultural receipts (Wyoming Agricultural Statistics Service, 1996).

Population change on unincorporated lands has not occurred uniformly across the state. Counties with more public lands tended to grow the most. The western portion of the state grew faster than the remainder from 1990 through 2000 (US Department of Commerce, Bureau of Census, 1996; Taylor, n.d.). Generally, in-migrants to western wilderness counties tend to be better educated, have professional occupations, have higher incomes, are younger and have lived previously in more populated places than area residents (Rudzitis and Johansen, 1989). These immigrants seek amenities in terms of improved climate, recreation, scenery, and environmental quality (Rudzitis and Johansen, 1989; for a Wyoming case see McLeod et al., 1998). They are in a favorable position to out compete agriculturalists for rural land. This is demonstrated by ranchettes, small acreage residential fragments of former ranches, found all over the western US and particularly in the Rocky Mountain region (Long, 1996; Reibsame, 1999).

4. Selective review of land value models

The literature examined reveals various components of hedonic models regarding land values. Agricultural land values are related to such attributes as productivity, distance to markets, and improvements (Xu et al., 1993, 1994; Torell and Doll, 1991). Urban and rural amenity attributes are analyzed in several articles. Few to date have incorporated the spatial specificity afforded by GIS measurement (see Kennedy et al., 1996; Geoghegan et al., 1997).

Garrod and Willis (1992) examined neighborhood or environmental characteristics of countryside parcels in the UK using a hedonic price model. Measured attributes were compared to perceived attributes. The view (of woodlands, for example), as well as the presence of water, was important. McLeod (1982) used a bid-price approach to determine marginal willingness-to-pay for urban residential properties in Perth, Australia. River view, in addition to water and park access, was important.

Spahr and Sunderman (1995) used Wyoming ranchland sales data to model the contribution of scenic and recreational quality to agricultural land price. Low, medium and high quality amenity levels, based on the judgment of area appraisers, were represented by indicator variables in their statistical model. These variables were statistically significant with high scenic quality contributing to higher sale price. Spahr and Sunderman (1998) examined agricultural land prices in the west using a hedonic approach. They found that uniform taxation of agricultural lands based on productive capacity encouraged speculation. Taxes paid on non-scenic parcels subsidized scenic parcels, in that overall market values diverged based on the presence of valuable non-agricultural attributes. The scenic value variables were indicator variables multiplied by the deeded acres across little, good, or great scenic levels, which were determined by area appraisers. Scenery was significant in explaining land values. GIS was not employed in either study to specify or quantify the scenic land attributes of individual parcels.

Bockstael (1996) estimated a hedonic model in order to predict probabilities associated with converting undeveloped land to developed lands. Important variables included lot size, public services, zoning, proximity to population centers and variables associated with the percent of agricultural use, forest lands and open space in the Patuxent watershed. Bockstael's (1996) model contributes to understanding land use behavior and parcel value.

A hedonic rural land study using GIS was provided by Kennedy et al. (1996). The analysis identified rural land markets in Louisiana based on economic, topographic and spatial variables. GIS was used for defining distance to market as well as soil type variables.

Geoghegan et al. (1997) developed GIS data for two landscape indices and incorporated them in a hedonic model for Washington, DC, suburban properties. Their measure of fragmentation is defined as perimeter to size ratio. The landcover measure is an index of land use type that is a surrogate for flora and fauna habitat. They provide an insightful array of landscape indices.

The approach provided in this paper expands the above-mentioned research. GIS is a valuable data source for HPM. Parcel-specific spatially defined attributes are quantified and modeled as determinants of land values. The location and amount of a particular amenity affords greater validity in statistical estimation and potentially more accurate estimation of attribute values derived from hedonic models.

5. Data

Data for this analysis came from appraisal data sheets for transacted land sales during 1989 through 1995 used by Bastian et al. (1994) and Bastian and Hewlett (1997) to assess Wyoming's agricultural land market. Approximately 1200 sales were screened for complete legal descriptions and data that allowed accurate measurement of GIS and agricultural variables hypothesized as important. A random sample was then drawn from these screened sales for each region, with approximately equal observations from each, given project budget constraints.

Past research indicates agricultural land values are a function of both agricultural and amenity variables given various demands for rural lands. The variables used in estimating the HPM are summarized in Table 1. The dependent variable of the model (CDACRE) is the nominal price per acre. CDACRE in nominal terms is negatively correlated with the GNP implicit price deflator. Cattle prices rose through 1993 and then fell thereafter. Bastian and Hewlett (1997) found that average agricultural land prices in Wyoming rose and fell in a similar fashion. This was particularly true for larger parcels. Thus, CDACRE was not deflated based on concerns this would introduce spurious measurement error into the dependent variable. The use of nominal sale price follows hedonic estimation in Spahr and Sunderman (1995, 1998) and Xu et al. (1993, 1994). TREND is included to account for price movements over time.

Table 1
Variable identification, description and hypothesized sign

Variable	Hypothesized sign	Variable description/definition
CDACRE	(dependent)	Total ranch price in dollars divided by deeded acres (average per acre price by parcel).
PASTMEDW	Positive	Productivity rating of all pasture and meadow lands on-parcel, measured in AUMs per acre.
IRIGAUAC	Positive	Productivity rating of all irrigated lands on-parcel (both sprinkler and gravity irrigated), measured in AUMs per acre.
TOTAUMS	Negative	Total carrying capacity of property, including deeded acres and assured leases, measured in AUMs.
TOTAMSQ	Negative	TOTAUMS squared.
RRUAPER	Positive	Percentage of total AUMs of carrying capacity coming from railroad leases.
PUBAUPER	Indeterminate	Total AUMs coming from BLM or state range which are an assured lease with the sale of the property divided by total AUMs and multiplied by 100. Note: This percentage can be more than 100.
SIMPINDX	Positive	Simpson's diversity index (0–1) multiplied by 100. This number can then range between 0 and 100.
STRMAC	N/A	Meters of stream on the property divided by deeded acres.
FISHPROD	N/A	Fish productivity average index on the property. The index comes from a Wyoming Game and Fish coverage.
FISHVALU	Positive	STRMAC multiplied by FISHPROD, providing a measure of fishing density per acre.
IMPDOLAC	Positive	Total dollar of improvements divided by deeded acres.
ELKACPER	Positive	Acres of spring–summer–fall and winter yearlong elk habitat divided by deeded acres.
TOWND	Negative	Distance from edge of property to nearest incorporated town of 2000 inhabitants by road.
TREND	Positive	Trend variable for years in sample of 1989–1995.
REGN	N/A	0 or 1 indicator variable for two regions in state, 1 being high amenity Western region of state, 0 being rest of state.
REGSIMP	Positive	Interaction variable, SIMPINDX*REGN.
REGFISH	Positive	Interaction variable, FISHVALU*REGN.
REGELKPR	Positive	Interaction variable, ELKACPER*REGN.

The measures of agricultural productivity (see Table 1) used are meant to address scaling issues associated with parcel size (see Parsons, 1990). Those agricultural production attributes hypothesized to affect price are PASTMEDW (pasture and sub-irrigated meadowlands); IRIGAUAC (irrigated croplands); TOTAUMS (operation size); IMPDOLAC (on-parcel improvements); and leased land (RRUAPER and PUBAUMS). The former is railroad land interspersed with private, state, and federal lands. The average value of railroad grazing leases in Wyoming tends to be greater than those found on public lands from 1990–1995 (Bastian et al., 1994; Bastian and Hewlett, 1997).

Important amenity components include consumptive and non-consumptive values of terrestrial wildlife, availability of water-related recreation and water quality indicated by trout habitat, accessibility and scenic amenities (see Appendix A for GIS protocols developed to quantify variables in these categories). Accessibility to towns is important in that it provides cultural and shopping opportunities to rural residents. The town population threshold of 2000 is chosen due to size thresholds that are related to the presence of various retail trade and service opportunities in Wyoming (Taylor and Held, 1998). Shonkwiler and Reynolds (1986) support the inclusion of such a variable as a proxy for unspecified, unknown non-agricultural amenities and services.

View characteristics examined in this analysis include total view, relief, diversity and the amount of edge between land cover classes (Germino et al., 2001). These view variables include those that were related to view cognition and preference (Gobster and Chenoweth, 1989; Kaplan et al., 1989; Steinitz, 1990; Baldwin et al., 1996; Hammitt et al., 1994; Bishop, 1996) and that could be calculated with the available data. Land cover diversity, as measured by Simpson's Index (Bar-

Table 2
Means, minimums and maximums for dollars per acre for agricultural land and agricultural production and GIS amenity variables in Wyoming ($N = 138$)

Variables	Mean	SD	Minimum	Maximum
CDACRE	430.655	442.630	28.538	2602.230
PASTMEDW	1.271	1.465	0.000	6.000
IRIGAUAC	1.600	3.493	0.000	12.500
TOTAUMS	1445.347	1990.008	96.000	12480.000
RRAUPER	0.317	2.991	0.000	33.753
PUBAUPER	6.388	15.776	0.000	83.034
SIMPINDX	45.430	11.966	3.077	61.857
REGSIMP	22.830	26.292	0.000	61.857
FISHVALU	2.254	5.578	0.000	43.839
REGFISH	1.604	5.115	0.000	43.839
IMPDOLAC	36.315	110.141	0.000	845.000
ELKACPER	13.352	31.504	0.000	100.000
REGELKPR	10.047	28.224	0.000	100.000
TREND	4.920	1.529	1.000	7.000
TOWND	34.480	27.546	0.000	110.237

bour et al., 1980), is used as a proxy to indicate the view composition. The view composition, rather than types of species, is used in the calculation for this analysis (see Geoghegan et al., 1997, for a nice description of alternative landscape composition indices). The index is calculated as follows:

$$D = 1 - \sum_{i=1}^{l} (p_i)^2 \qquad (2)$$

where D is the diversity index ranging from 0 to 1 (0 being no diversity and 1 being maximum diversity), l is land coverage type, and p_i is the proportion of view area occupied by each land type, which can be seen from the centroid of the parcel.

Specifically, the amenity variables are elk (an important big game species in Wyoming) habitat for each land sale (ELKACPER);[2,3] fish habitat density (FISHVALU);[4] urban goods and services access (TOWND); and view composition (SIMPINDX). Interaction terms are constructed for view as well as for trout and elk habitat (REGSIMP, REGFISH and REGELKPR). These are the product of an indicator variable for region 1 multiplied by the respective amenity measures.

Descriptive statistics of these variables are provided in Table 2. All of the variables described are thought to enhance the (per acre) sale price and yield a positive coefficient, except TOTAUMS (parcel size). Per acre sale price is thought to decrease with size and thus lead to a negative estimated coefficient.

[2] Estimated expenditures for all elk hunters in Wyoming grew by 22.6% from 1990 through 1995, with 1995 hunter expenditures exceeding $29 million (Wyoming Game and Fish Department, 1996). Total expenditures on elk hunting exceed expenditures for hunting any other species in the state (Wyoming Game and Fish Department, 1996).

[3] Spring–Summer–Fall and Winter–Year-long habitat designations were chosen as they were thought to maximize hunting and/or viewing opportunities (Lutz, 1998; Wyoming Game and Fish Department, 1998).

[4] Estimated expenditures on sport fishing in Wyoming grew by 11.7% from 1990 through 1995 with 1995 angler expenditures being over $225 million (Wyoming Game and Fish Department, 1996). Additional evidence on the importance of trout fishing in the Rocky Mountain region includes willingness-to-pay estimates by Dalton et al. (1998) as well as Duffield and Allen (1988), indicating the value of regional trout fisheries.

Table 3
Coefficient estimates and likelihood ratio tests for model specifications ($N = 138$)

Variable	Linear coefficient	Semi-log coefficient	Quadratic coefficient
Intercept	−360.952 (0.004)*	3.534 (0.000)	−358.176 (0.004)
PASTMEDW	64.907 (0.009)	0.246 (0.000)	64.665 (0.010)
IRIGAUAC	40.018 (0.000)	0.090 (0.000)	40.761 (0.001)
TOTAUMS	−0.038 (0.000)	-0.7×10^{-04} (0.009)	−0.048 (0.236)
TOTAMSQ	–	–	0.1×10^{-05} (0.772)
RRAUPER	13.012 (0.000)	0.014 (0.159)	13.241 (0.000)
PUBAUPER	−1.549 (0.260)	−0.005 (0.263)	−1.438 (0.342)
SIMPINDX	5.527 (0.000)	0.021 (0.000)	5.600 (0.000)
REGSIMP	4.263 (0.043)	0.005 (0.237)	4.334 (0.050)
FISHVALU	4.057 (0.327)	0.025 (0.071)	4.418 (0.321)
REGFISH	28.456 (0.010)	0.014 (0.374)	27.981 (0.014)
TREND	46.936 (0.010)	0.071 (0.067)	46.722 (0.010)
IMPDOLAC	0.707 (0.035)	0.002 (0.000)	0.707 (0.033)
ELKACPER	0.751 (0.102)	0.005 (0.001)	0.722 (0.116)
REGELKPR	−2.780 (0.013)	−0.005 (0.079)	−2.721 (0.016)
TOWND	1.847 (0.070)	0.005 (0.024)	1.852 (0.068)
R^2	0.604	0.617	0.604
Adj-R^2	0.559	0.573	0.556
Breusch–Pagan X^{2a}	154.224** (0.001)	22.733** (0.100)	154.397** (0.001)
Likelihood ratio	127.831 (0.000)	1816.557 (0.000)	127.916 (0.000)

[a]The Breusch–Pagan chi-square test indicates the presence of heteroscedasticity prior to any adjustment. The values below the chi-square indicate the associated t values.
*Values in parentheses below coefficient estimates are P values on the t statistics. **Results adjusted using White's consistent covariance estimator (1980). OLS results are given, but with revised, robust covariance matrix (Greene, 1998). NOTE: The largest condition index does not exceed 21 for any variable regardless of functional form.

6. Estimation diagnostics issues

Several functional forms are estimated (Table 3).[5] The general model is thought to be well specified, as evidenced by both the robustness of the arguments and the highly significant goodness-of-fit measures across the functional forms. A simple linear model and a semi-log model (CDACRE logged) are equally preferred based on the goodness-of-fit measures, on the significance of the land attributes in explaining per acre parcel price, and on the ease of interpretation. The quadratic specification is not deemed adequate since the chief modifications to the base model, size (TOTAUM) and size squared (TOTAMSQ), are insignificant.

A Box–Cox transformation of the model was considered (Box and Cox, 1964), but not reported due to the fact that most of the explanatory variables in the model can take on zero values and cannot be transformed (Greene, 1993).[6] Moreover, logarithmic transformations of the independent variables were not pursued due to the potential for zero values.

Diagnostics indicate no significant multicollinearity problems with the two preferred models. A condition index score was estimated for the variables in the OLS estimated models as pre-

[5] Nonlinear forms of the explanatory variables ELKACPER and TOWND are tried but do not improve the explanatory power of the models as indicated by reduced goodness-of-fit compared to the reported models. Those results are not reported here in the interest of brevity.

[6] Cassel and Mendelsohn (1985) indicate the potential for misleading and non-interpretable estimates when many of the independent variables can take on zero values. Cropper et al. (1988) find that simple linear models perform well compared to other functional forms, based on Monte Carlo simulations. Milon et al. (1984) used a Box–Cox transformation to test different functional forms of hedonic models explaining land values in Florida and found that the linear and semi-log were among the best specifications out of seven estimated functional forms across three different locations.

scribed by Belsley et al. (1980).[7] Belsley (1991) and Gujarati (1995) indicate serious multicollinearity problems likely exist with condition index scores over 30. All condition index scores were less than 21. Moreover, variance inflation factors were estimated for the models reported. Only one value was greater than 10 (10.87), which is the rule of thumb threshold recommended by Gujarati (1995). A correlation analysis of the independent variables indicated only one pair of variables had a higher coefficient than 0.55 (0.88). All of these diagnostics point toward multicollinearity not being a significant problem in these models.

The model is comprised of cross sectional data wherein the dependent variable varies greatly relative to the independent arguments. The chosen units of the independent variables are intended to reduce the potential effects of heteroscedasticity thought, *a priori*, to be present in this data set. Greene (1993) indicates that heteroscedasticity arises primarily in the analysis of cross sectional data. No *a priori* form of the heteroscedasticity is hypothesized based on examination of the data.

The Breusch–Pagan statistic from White's test shows the presence of heteroscedasticity (1980). White's consistent estimator of the covariance matrix is employed to provide consistent estimates of the covariance matrix of the estimated β's (Greene, 1998).[8,9] The covariance estimator provides consistent outcomes in testing linear hypotheses of the estimated coefficients. This is critical since the two preferred models are linear in nature and hypothesis tests regarding the significance of the parameter estimates is the primary concern of this research.

HPM analyses are inherently spatial. Spatial correlation is an efficiency issue in estimation that may lead to incorrect test of hypotheses results. It occurs due to omitted unobserved land characteristics that are spatially correlated both to the dependent variables and to each other (see Bockstael and Bell, 1998). Statistical tests and remedies can be obtained (see Anselin, 1992, for a description of SPACESTAT). See also Anselin (1988, 1990), Anselin and Hudak (1992) as well as Getis and Ord (1992) for a more thorough discussion of these diagnostic and estimation techniques.

Lagrange Multiplier tests for spatial error and spatial lag dependence are performed for the simple linear model. A Lagrange Multiplier test is used to test the null-hypothesis of no spatial correlation. Neither spatial dependence nor spatial error correlation is present when using a 400 mile distance band for the spatial weight matrix ($LM_{lag} = 0.5294$; prob. = 0.4511; $LM_{err} = 0.5679$; prob. = 0.4668). This distance describes a large but heterogenous Wyoming agricultural land market.

The data exhibit heteroscedasticity and may have spatial correlation problems when considering distance bands of less than 400-miles. However, the robustness of traditional diagnostics for spatial correlation in the presence of heteroscedasticity is questionable (Anselin and Rey, 1991). A review of the literature indicates a lack of a joint remedy for these conditions when the nature of the heteroscedasticity is not known. When maximum likelihood estimation procedures were used (see SPACESTAT, Manual, Anselin (1995)) to address potential spatial correlation, diagnostics indicated significant heteroscedasticity with Breusch–Pagan statistics in excess of 100. It was deemed that the heteroscedasticity was a more serious problem than potential spatial correlation.[10]

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[7] The condition number is estimated as the square root of division of the maximum characteristic root by the minimum characteristic root (Belsley et al., 1980). See Greene (1993) for additional discussion on the estimation of this diagnostic.

[8] The covariance matrix for b is $\sigma^2(X'X)^{-1}X'\Omega X(X'X)^{-1}$, and White's consistent estimator is $(X'X)^{-1}[\Sigma_i e_i^2 x_i x_i'](X'X)^{-1}$. "LIMDEP produces this estimator as part of the REGRESS procedure..." (Greene, 1998, pp. 291).

[9] Transformations such as logarithms for the independent variables were not used given the large incidence of variables which could take on zero values.

[10] Future research needs to resolve problems common to most HPM estimation using spatially related data, such as multicollinearity, heteroscedasticity and or spatial correlation issues. The techniques currently available to deal with heteroscedasticity and spatial correlation jointly are limited to techniques assuming *a priori* knowledge of the nature of the non-constant variance of the errors.

7. Empirical results

The following results are reported for the simple linear and semi-log estimations, respectively. The signs on the significant GIS constructed amenity variables meet a priori expectations across the two preferred models, save REGELKPR (Table 3). REGELKPR has a negative coefficient indicating decrease in western Wyoming ranch or farmland value due to the presence of elk habitat. Possible rents extracted from fee hunting for elk in western Wyoming are diminished due both to elk occupying public land during the hunting season and the large amount of public land there (81% of region 1). Elk are a source of property damage both to fences and hay stacks; they may be viewed as a nuisance (Van Tassell et al., 2000). Elk habitat (ELKACPER) state-wide is positively related to sale price. Elk state-wide offers rent seeking opportunities for rural landowners due both to scarcity and trespass. The central and eastern parts of the state have less elk and public land (proportionately more privately controlled land).

The level of view and trout habitat variables help explain parcel price. Variables signifying trout habitat for the simple linear estimation are significant in the western part of Wyoming (REGFISH) at $\alpha = 0.01$ level but not state-wide (FISHVALU). The latter outcomes indicate the regional prominence of the afore-mentioned trout streams in comparison to the balance of the state. The most interesting result of the amenity variables is the significant and positive coefficients of scenic amenities state-wide (SIMPINDX) at $\alpha = 0.01$ level and in region 1 (REGSIMP) at $\alpha = 0.000$ level for the simple linear model. The results indicate that view diversity, rather than uniformity, is more highly valued. A diverse view composition is indicative of nearby diversity of landscapes, landforms and associated wildlife habitat. The view diversity could be valued by the current owner as well as potentially bearing future gains should the land be developed residentially. The regional variables for view (REGSIMP) and fish habitat (REGFISH) drop out of the semi-log estimation. It is thought that the compressed scale of the dependent variable is not sensitive to regional variation as in the simple linear model. State-wide fish habitat is significant in the semi-log but not so in the simple linear form. These outcomes coincide with both Spahr and Sunderman's (1995) as well as Spahr and Sunderman's (1998) results.

Distance to social/urban amenities (TOWND) is significant in both models. It indicates that the more distant and rural the agricultural property, the higher the per acre price. This supports the potential demand by agricultural interests due to less urban-originated nuisance claims arising from agricultural practices. The possible demand by amenity seekers who enjoy untrammeled trout streams, elk habitat, and scenic views also is suggested.

The signs on the significant agricultural production variables meet *a priori* expectations. The agricultural production variables associated with grazing (PASTMEDW) and irrigated crop production (IRIGAUAC) are significant for both models. Capital improvements (IMPDOLAC) also are significant for both models in explaining sale price. RRAUPER is positive and significant in the simple linear model, indicating the importance of secure (private) grazing leases. RRAUPER is not significant in the semi-log model, possibly due to the insensitivity of this functional form to the few railroad leases. Ranch or farm size (TOTAUMS) has a negative coefficient and is significant in both estimations. The sign indicates the diminishing marginal value (measured on a per acre basis) associated with increasing size. These findings are consistent with Torell and Doll (1991) and Xu et al. (1994).

While the variable associated with public forage (PUBAUPER) is not significant, it is interesting to note that the sign is negative. This result is compatible with previous research. Torell and Fowler (1986) found that proposals for increasing grazing fees on federal lands and actual increased grazing fees on New Mexico State trust lands lead to a substantial percentage decline in ranch values for ranches highly dependent upon public land forage. Bastian and Hewlett (1997) concluded that as the public-originated percentage of total forage for a ranch increased beyond 24% the price per animal unit declined for ranchlands sold during 1993 through 1995.

Non-agricultural interests (amenity seekers) would not be expected to associate value with federal grazing leases. Subleasing of federal allotments is generally prohibited and opportunities to secure resale or rents by non-grazing interests are minimal.

TREND is positive and significant. Wyoming ranch and particularly farmland prices rose during the study time period (Bastian et al., 1994; Bastian and Hewlett, 1997).

8. Conclusions

The demand for amenities such as outdoor recreation, scenery and open space is expected to grow as population migration to less urban areas continues. These pressures will increase the competition for agricultural lands. Results of this study indicate that remote agricultural lands, which include wildlife habitat, angling opportunities and scenic vistas, command higher prices per acre than those which primarily possess agricultural production capacity. Amenity rich lands may be at risk for conversion from agricultural and open space function to residential use.

The contribution of this study is to utilize estimated variables derived from GIS measures, the values of which are uniquely specific to individual land parcels. The GIS variables provide a means to quantify amenity attributes and the opportunity to include them in a hedonic price model. The results point to an improved hedonic price model specification for agricultural lands, particularly for the Rocky Mountain and Great Basin regions. The GIS data development provides more explicit variables and model specifications than qualitative representations such as ordinal ranking of land attribute levels or indicator variables signaling the presence of amenities. Estimation of hedonic models using such techniques stand to provide more accurate value estimates of environmental amenities. This is important baseline information for policies intended to preserve environmental amenities, improve valuation of agricultural conservation easements, and reduce land use conflict resolutions.

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Appendix A

Distance to Town

All parcels were first digitized. The centroid label of each parcel was calculated using the Arc centroid label command. The centroid labels were then copied into a point coverage that was used to calculate distance from the centroid to the nearest town with a population ≥ 2000.

The shortest path (along existing roads) to the closest town center with a population ≥ 2000 was calculated in the following steps. Three coverages were required which include the parcel point coverage; a road coverage derived from the TIGER state-wide road coverage that has interstate highways, state highways, connecting or county roads and neighborhood roads (Spatial Data and Visualization Center, 1997); and a coverage, derived from the state-wide CITY coverage (Spatial Data and Visualization Center, 1996a), for towns with populations ≥ 2000.

1. Distance from the centroid of the largest polygon in a parcel to the closest node in a road coverage was first calculated using the Arc command NEAR.
2. The city with a population ≥ 2000 nearest (as the crow flies) to each parcel centroid label was located and the distance from the city label to the node nearest the city in the road coverage was calculated using the Arc command, NEAR.

3. The Arcplot command, PATH, was used to calculate the shortest path (along roads in the road coverage) from the node closest to each parcel centroid to the node closest to the nearest city with a population ≥ 2000. PATH was unable to generate a path for a few of the parcels because the closest node (in the road coverage) to the parcel centroid was on a dead end road. The NEXT closest node to the centroid in this case was manually selected using the distance ruler in ArcEdit. Once this node was determined it was used with the PATH command.
4. Distances generated in steps 1 through 3 were added together to get the total distance from the road node closest to each parcel centroid to the road node closest to the label of the nearest city.

On-parcel Elk Habitat

Total area of elk habitat on each sale parcel was calculated using the Arc IDENTITY command, which calculates the geometric intersection of two coverages. Each sale coverage was intersected with a coverage containing both Winter–Year-long (WYL) and Spring–Summer–Fall (SSF) elk habitat. Descriptions of the two habitat types used are listed below (taken from the Wyoming Game and Fish Department, 1998 coverage metadata):

Winter–Year-long Habitat

A population or portion of a population of animals makes general use of the documented suitable habitat within this range on a year-round basis. But during the winter months (between 12/1 and 4/30), there is a significant influx of additional animals into the area from other seasonal ranges.

Spring–Summer–Fall Habitat

A population or portion of a population of animals use the documented habitats within this range from the end of the previous winter to the onset of persistent winter conditions (variable period, but commonly from May through November).

Viewshed Analysis

(1) Area of viewshed

View area was calculated for each parcel centroid label using the Arc VISIBILITY command. VISIBILITY requires an in_lattice (DEM), and in_cover (point coverage containing the observer location), an out_cover (this is the polygon coverage that is created by VISIBILITY and contains all regions that can be seen from the observation point specified in the in_cover).

The DEMs used in this analysis were adjusted for vegetation height. A land cover coverage was obtained for WY and surrounding states and the land cover types were combined into a simplified classification containing only 10 types. The polygon coverages were converted to 30 M grids, and the cell values for the grid were then reclassed into land cover height (an average height was assigned to each land cover type). These land cover heights were then added to the DEMs for each state to create a DEM that was corrected for vegetation height.

The resulting visibility coverage shows all visibility polygons that can be seen from the centroid of the parcel at an observer height of 2 m.

(2) Characteristics of Viewshed

The viewshed of each centroid label was draped with the combined land cover coverage and the area of each land cover type, as well as the amount of 'edge' (length of arcs between each land cover type) was calculated using the SURFACEDRAPE command in ARCPLOT, in order to characterize each parcel view (Spatial Data and Visualization Center, 1996c).

SURFACEDRAPE requires and x, y, an z coordinate for each observer point (in this case, the x and y values are the locations of the centroid label for each parcel, and the z value is elevation (+2 M) derived from a surface lattice created by the DEM (adjusted for vegetation height) of the centroid label.)

On-parcel Trout Streams

To calculate on-parcel trout productivity, each parcel coverage was intersected (using the Arc command INTERSECT) with a rivers coverage. The rivers coverage is a subset containing streams of 3rd order or higher of the Wyoming Gap Analysis 1:100 000-scale hydrography coverage (HYDRO) for Wyoming (Spatial Data and Visualization Center, 1996b). No digital coverage that contains stream names or trout productivity for Wyoming is currently available. The WY Game and Fish Trout Stream Classification Map (1991) was used to assign stream names and class to each stream arc in each intersected coverage. WY Game and Fish provided a database containing trout productivity, stream name, and township and range information, and this was used to manually assign productivity to each stream arc.

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