Measuring Environmental Effects on Property Values: Analysis of Spatially Variable Relationships

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Abstract

The objective of this paper is to estimate the relationship between house prices and environmental attributes across a diverse metropolitan area. The Auckland region comprises seven local units of government; four are classified as cities and three are classified as districts. Districts are located around the urban fringe. The initial data set is based on over 10,000 sales recorded during 2004. Limited environmental attributes and socio-economic data drawn from census records were available. A global hedonic model shows *inter alia* that building floor area and income are significant determinants of market price. Parameter estimates for environmental variables, such as contour and water view, also turn out to be significant. The overall explanatory power of the global model is low and a large percentage of the variance in house prices remains unexplained. Some of the unexplained variance arises from a failure to model the heterogeneity of the cities and the contribution of distance to house buyer decisions. By enriching the data set with spatial information and imposing more structure on the regional model we are able to better explain cross-sectional differences in house prices.

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1.0 Introduction

The hedonic property price method has been used extensively to estimate the value of the flow of services associated with environmental amenities. Mahan *et al.* (2000) estimate the value of wetland characteristics using the hedonic price method. They find that a property's value increased when the size and the proximity of the nearest wetland increased. They also find that wetlands influence property values differently than lakes, rivers and parks. The preservation of open space is often justified by attributing values to biodiversity, open space and wildlife habitat. Geoghegan *et al.* (1997) find that the positive impact of open space on land values switches to a negative impact as distance increases. Rather than aggregating up over the various dimensions of open space, Irwin (2002) recognises its heterogeneity and finds that some dimensions exert different influences on property values. For example, pastureland is found to generate a significantly greater spillover effect on residential property values than does the spillover effect of neighbouring forests. Other hedonic studies have estimated the value associated with gradients of air quality (Smith and Huang 1993), water bodies with varying conditions of quality (Leggett and Bockstael 2000), non-residential land like parks and urban green areas (Li and Brown 1980; Morancho 2003), and disamenities like oil spills, toxic dumps, noise pollution (Espey and Lopez 2000), and natural hazards (Maani and Kask 1990).

Hedonic studies have been shown to overestimate the benefits of an improvement or underestimate the cost of deterioration (Markandya 1992; Brookshire 1982). Experimental tests suggest that the overestimation can be as much as two- to three-times the true willingness to pay for the benefit (Bishop and Heberlein 1979). One of the reasons for this is that theory offers little guidance on the appropriate functional form for the hedonic price function. Using a flexible functional form can address this but using too general a form may not be robust when the function is mis-specified (Cropper *et al.* (1993).

In much of the previous work, the location of a property has been conceived in terms of relative neighbourhood quality measures and fixed location attributes. Accessibility has been the single most important measure of location in hedonic house price studies and is commonly gauged by various measures of access to the central business district (CBD). More recently, access to non-CBD centres has also been considered. Neighbourhood quality has typically been quantified by surrogate measures, usually generated from census data. For example, Dubin and Sung (1990) classified neighbourhood quality measures using three broad categories relating to social economic class, local municipal services, and racial composition.

Locational attributes are in essence measures of locational externalities. As such they can be positive or negative. Frequently a single amenity may emit both positive and negative externalities (Li and Brown 1980). For example, a local shopping centre imposes negative externalities in the form of traffic congestion and noise pollution and positive externalities through convenience to the local residents. Most externalities are local in their impact, with a distance decay effect in their extent and intensity. Generally, households closest to the source of the externality will be the most affected, with the intensity of this effect diminishing with distance. The larger the shopping centre, the greater the intensity and range of these effects. In cases like shopping centres the decay effect may not be a monotonic function of distance. The optimal location can be viewed as a trade off between the benefits of increased accessibility and the costs of proximity.

Urban space is divided up by transportation routes, housing stock and land use into discrete units and property prices can therefore be conceived as contiguous rather than continuous. However these units can be nested into a hierarchy operating at several spatial scales with the most basic scale as the individual property. Properties are nested into streets, and streets into neighbourhoods. Orford (1997) has argued that the spatial structure of property values should reflect this structure of urban space and that the spatial dynamics of the housing markets should be conceptualised as being multi-scaled, or multi-levelled. The implication of this for hedonic house price modelling is that a differentiation should be made between compositional and contextual effects of location on house price. Contextual effects are the differences a place makes, such as neighbourhood quality, whilst compositional effects are the differences caused by the variations in the housing stock within each place. Differentiating between compositional and contextual effects is difficult in the traditional specification of the hedonic model, since ordinary least squares regression presumes only one single level of variation.

This problem can be overcome by specifying the hedonic model, not as varying at a single level, but as varying simultaneously over a number of levels. This is the basis of multi-level modelling, a recent statistical technique that allows multi-hierarchical space to be explicitly incorporated into standard econometric models. Multi-level modelling of house prices have been investigated in the work by Jones and Bullen (1993, 1994), and these possibly form the basis of the next generation of hedonic house price models. However, in such models urban space is still built in context free. Orford (1997) has proposed an approach to building in location externalities using GIS analysis and developed a hierarchy of location externalities operating at different spatial scales.

In this paper we use the standard hedonic model to estimate the relationship between residential house prices and structural characteristics of the house, neighbourhood features, location and socioeconomic variables. The paper is organised as follows. First, we briefly discuss the hedonic pricing model as a means of estimating the marginal value of environmental attributes. The discussion canvases the range of problems that can arise from when estimating the hedonic function. Results of the model are presented and the marginal values for various environmental attributes are derived. The paper concludes with a general discussion and suggestions for further research.

2.0 The Hedonic Model

Rosen's (1974) seminal article provides the theoretical foundations for most of the empirical research that uses hedonic pricing to value the flow of services associated with environmental amenities. Simply stated, the hedonic price function represents a locus of equilibria between buyers and sellers in the market, where $P(x)$ is the price of the good with a vector of characteristics x. For example, we might include proximity to a park (x_1) in the vector of attributes. The marginal implicit price of proximity is measured by $\partial P / \partial x_i$. Given that the location of a house is fixed, the value spillover, as recognised in the market, is capitalised into market price. Clearly, not all values associated with environmental amenities can be captured by the hedonic equation. For example, the marginal implicit price is unlikely to capture important non-use values (Freeman, 1993).

We specify the hedonic residential model as follows:

$$P_i = f(H_i, N_i, T_i, S_i; \alpha, \beta, \gamma, \delta) \tag{1}$$

where P_i is the residential sale price of the i^{th} property, H_i is a vector of structural characteristics of the house, N_i is a vector of neighbourhood variables, T_i is a vector of topographical attributes, and S_i is a vector of neighbourhood socio-economic characteristics, and α, β, γ, δ are the respective parameter vectors to be estimated.

A number of econometric issues arise when estimating the above hedonic model. The most notable issues recognised in the literature include model specification and functional form, identification (Ekeland *et al.* 2002, Irwin 2002), and spatial error autocorrelation (Anselin 1988). Theory also offers little guidance in determining exactly what attributes to include in the hedonic model (Ohsfeldt 1988). Ideally model specification and functional form should be guided by economic theory. However, theory offers little guidance beyond the signs expected for estimated coefficients. This is demonstrated in the literature, where the lack of widespread agreement has resulted in a diverse range of variables entering the hedonic specification (Graves *et al.* 1988) and the potential for multi-collinearity is often quoted. A number of the environmental attributes being estimated are in themselves multi-attribute goods. For example, urban green areas provide recreational and aesthetic amenity, act as physical boundaries between urban units, and absorb carbon dioxide and noise pollution. Incomplete specification of the model by exclusion of highly correlated compound variables that have multiple effects on purchasers has the potential to bias coefficient estimates (Li and Brown 1980; Legget and Bockstael 2000). Choice of functional form is typically guided by empirical evidence.

The challenge of identifying the effects of environmental attributes arises from the potential endogeneity of neighbourhood variables. For example, if we include open space in the vector N_i then it too is part of the market for residential land and subject to the economic forces that determine value and the estimated coefficient on open space will be biased. According to Irwin and Bockstael (2001) two identification problems arise. First, consider two properties i and j that have varying amounts of open space that may be developed. The value of property i is a function of the value of property j and the value attributed to open space around i, which is a function of property *j's* value. In this case the value of open space is endogenous. Second, if the explanatory variables are exogenous, but spatially autocorrelated, then the efficiency of the estimators drops; the standard errors are biased but the estimated coefficients are not biased. However, as Irwin (2002) points out, if a right-hand-side variable is endogenous then they will be spatially correlated with the error term creating a second source of bias.

Other difficulties also arise. Results from hedonic studies are sensitive to changes in information available to property purchasers. The method assumes households are fully aware of the costs or benefits produced by an environmental attribute and are able to adjust their residential location to secure their desired combination of environmental attributes. Similarly the application of the hedonic approach under conditions of risk and uncertainty have been shown to be sensitive to subjective probability of hazardous events, which can differ from objective probability (Brookshire *et al.* 1985; Smith and Johnson 1988; Maani and Kask 1990). Discrete changes in environmental attributes that are widespread shift the hedonic price function and the total change in predicted property values serves only as an upper bound for benefits (Bartik 1988), while changes confined to small areas are windfall gains or losses to the affected property owners equal to the total change in predicted property values (Palmquist 1991).

An alternative to the hedonic model's assumption of a continuous function relating the price of a good to its attributes, is the discrete choice approach which views the individual as choosing the property, out of a universal choice set, that maximises utility where utility is a funtion of product attributes. The discrete choice model avoids the problems around implicit marginal price estimation, but only by imposing a good deal of structure on the preference function. Cropper *et al.* (1993) have demonstrated that both approaches can perform equally well in estimating the marginal value of an attribute, but that the discrete choice approach performs better when attribute changes are non-marginal.

2.0 Study Area and Data

The study area comprises four cities (Auckland City, Northshore City, Manukau City, Waitakere City) within the Auckland region. Table 1 shows Auckland City having the largest population; North Shore City has the smallest area and the highest population density. Table 2 reveals different ethnic compositions across the four cities. Manukau City has the greatest percentage of Maori and Pacific Island residents; North Shore City is largely settled by people of European decent. On the surface, the cities are heterogeneous in terms of population density and ethnicity.

Table 1: Area and estimated resident populations

City	**Area km^2**	**Population June 2005**	**Share of NZ population**	**People per km^2**
Auckland City	633	425,400	10.4	672
Manukau City	683	298,200	8.1	488
North Shore City	129	212,200	5.2	1,648
Waitakere City	367	191,900	4.7	522

Table 2: Ethnicity, major groups, percentage of Census 2001 population

City	**European**	**Maori**	**Asian**	**Pacific Island**
Auckland City	64	8	19	13
Manukau City	50	16	15	27
North Shore City	80	7	13	3
Waitakere City	71	13	11	15

The residential sales data set consists of 5,864 single transactions of owner-occupied residential properties recorded between January 2004 and December 2004. Data obtained from Quotable Value New Zealand provided a record of sale price, house structural variables, topographical variables, and socioeconomic information recorded for the mesh-block in which the property was located. Using census data we were able to include count data for income and ethnicity. These data were further enriched by GIS data which included population density, distance to Auckland's CBD, distance to the coast, the nearest park, and the New Zealand deprivation index. The deprivation index was discarded because of correlation with other right hand side variables. The record of sales was deflated to December 2003 using the quarterly house price index (Quotable

Value, 2004). The variables used are described in reported in Table 3 along with their expected signs.

Table 3: Explanatory Variables: names and definitions

Variable Name	Description	Expected Sign
Structural variables (H)		
AGE	Age of house, years	Negative
LCR	Lot cover ratio, percentage	Unknown
Neighbourhood variables (N)		
DISP	Distance to park	Negative
DISC	Distance to coast	Negative
DCBD	Distance to Auckland CBD	Negative
Topographical variables (T)		
CONT	Dummy variable for contour (level = 1)	Positive
WVIEW	Dummy variable for water view (water = 1)	Positive
SVIEW	Dummy variable for scope of view (wide = 1)	Positive
	Socioeconomic variables (S)	
PCINC	Percent income < \$50k	Negative
PCEUR	Percent European	Positive
PDENS	Population density	Negative

3.0 Empirical Results

We set up the following panel model for the four cities:

$$p_{i,j} = \alpha_j + \beta' x_{i,j} + \varepsilon_{i,j}$$

Where

$p_{i,j}$ = the i^{th} property sale price in city j.

$x_{i,j}$ = $(H_{i,j}, N_{i,j}, T_{i,j}, S_{i,j})$

$\varepsilon_{i,j} \sim N(0, \sigma_\varepsilon^2)$.

Results from a simple pooled regression using linear price are shown in Table 5. In terms of the structural variables; the coefficients for *AGE* accorded with expectations and is significant. Of the neighborhood variables, both distance variables – *DISP* and *DCBD* -performed according to expectations. The topographical variables each had the expected sign although only *WVIEW* and *SVIEW* were significant. Finally, of the socioeconomic variables, the sign of the *PDENS* coefficient was positive but not significant. In short, property with a view of the sea, flat contour and wide view scope commanded a higher price. Income and ethnicity exerted a significant – negative and positive respectively – influence on price.

We then imposed more structure and estimated a panel model with a dummy variable for each. The panel model results are shown in Table 5. Compared with the pooled model, the only obvious change is the significance of *PDENS*. A possible explanation for the sign reversal can be derived from Table 1 which shows quite a range of population density across the four cities. Changing the functional form of the model to log-linear greatly improves the explanatory power of the model. The sign of each coefficient is consistent with those estimated using the linear model.

Table 5: Panel Analysis for Four Cities

Variables	**Linear Model**		**Log-linear model**
	OLS without Group Dummy Variables n = 5647	**OLS with Group Dummy Variables n = 5647**	**OLS with Group Dummy Variables n = 5647**
Constant	124,0132*** (73,505)		
Structural variables			
AGE	-85.7539*** (31.3382)	-74.5982*** (27.4349)	-0.8230E-04*** (0.1558E-04)
LCR	-0.6035E-02 (0.7000E-02)	-0.8435E-03 (0.5759E-02)	-0.1532E-09 (-0.1532E-08)
Neighborhood variables			
DISP	-0.1738** (0.7992E-01	-0.3252E-06*** (0.6728E-0)	-0.2218E-06*** (0.3822E-07)
DCBD	-0.4048* (0.2243)	-36.2777*** (2.6065)	-0.2825E-04*** (0.1480E-05)
Topographical variables			
CONT	23,112 (25,469)	47,794* (21,539)	0.4984E-01*** (0.4984E-01)
WVIEW	482,374*** (40,952)	500,338*** (34,043)	0.2828*** (0.1934E-01)
SVIEW	376,033*** (54,719)	373,770*** (45,180)	0.1938*** (0.2566E-01)
Socioeconomic variables			
PCINC	-11,598*** (747)	-8,481*** (653)	-0.7454*** (0.3715)
PCEUR	5,212*** (663)	5,838*** (573)	0.5376E-02*** (0.3258E-03)
PDENS	3.6864 (3.5128)	-22.910*** (3.7314)	-0.1429E-04*** (0.2119E-05)
Log-L	-85,487	-84,368	-3,159
R^2	0.1571	0.4330	0.6852

Note: ***, **, * = 1%, 5%, 10% levels of significance respectively.

Table 6: Test Statistics for the Log-linear Model

Model	**Log-Likelihood**	**R^2**
(1) $p_{i,j} = \alpha + \varepsilon_{ij}$	-6,422	0.0000
(2) $p_{i,j} = \alpha_i + \varepsilon_{ij}$	-4,220	0.5416
(3) $p_{i,j} = \alpha + \beta' x_{i,j} + \varepsilon_{ij}$	-5,797	0.1987
(4) $p_{i,j} = \alpha_i + \beta' x_{i,j} + \varepsilon_{ij}$	-3,159	0.6852
Hypothesis tests	**Chi-squared**	
(2) vs (1)	$\chi_{23} = 4{,}405$	
(3) vs (1)	$\chi_{12} = 1{,}251$	
(4) vs (1)	$\chi_{35} = 6{,}527$	
(4) vs (2)	$\chi_{12} = 2{,}121$	
(4) vs (3)	$\chi_{23} = 5{,}276$	

5.0 Discussion

Our aim in this paper was to investigate the multidimensional nature environmental attributes – broadly defined – on property values. Within the set of environmental attributes we were able to include data on aesthetics, such as sea views; contour; and, proximity to local parks. Other variables – such as proximity to the coast – were available. But in the case of proximity to the coast, most Aucklanders reside within a few kilometres of the coast and we found very little evidence that this impacted property prices. Results for the other explanatory variables – house attributes, distance to the CBD and socioeconomic variables such as income and ethnicity - are typical of many hedonic studies. The Auckland region comprises four of New Zealand's largest cities. The cities are distinguished *inter alia* by population density and ethnic composition.

A simple OLS regression on the pooled data set performed reasonably well in terms of the expectation for the signs of the coefficients. But the overall explanatory power of the model is low. In this respect the panel model is superior, while the signs of the coefficients remained pretty much in tact. The explanatory power of the panel model is greatly improved when we used a log-linear function. Our empirical analysis confirms that environmental variables in general have a strong positive impact of house values.

Moreover, we are able to estimate the relative impact of variables that combine to define the environmental attributes of a city.

This research could be extended in at least three ways. First, we have yet to fully tap into the data set relating to both structural and environmental variables. Second, the four cities are confined by a Metropolitan Urban Limit (MUL), which effectively limits urban sprawl. Given that we are able to identify sales within, and beyond, the MUL it would be possible to control for the effects of planning pressure on property prices. Third, it would be on interest to see if the expression of environmental variables has changed over time.

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