Factors affecting Residential Property Values in a Small Historic Canadian University Town

John Janmaat*
Department of Economics
Acadia University

December 15, 2005

Abstract

The town of Wolfville, Nova Scotia is a small historic community, economically dominated by Acadia University. It is located on the north slope of a ridge, affording views of the Minas Basin, at the eastern end of the Bay of Fundy. The upper boundary of the town is a major provincial highway. A set of sound level observations was used to generate average and peak sound level profiles for the town. Average and peak sound level, as well as presence of a view were included in a hedonic regression of property values. View and average sound level were not statistically related to home price. However, peak sound level is priced, with a one decibel increase reducing the average house price by about two percent. Beyond conventional variables such as age and living space, the zoning classification of the property was found to be highly significant, with homes zoned for single family residential only commanding the highest price. Given the high population of student tenants in Wolfville, tenants unlikely to live in areas zoned single family residential, these results suggests that rental externalities - either due to student tenants or landlord practices - are having a strong negative impact on property values.

JEL: R21, R31, R52

Keywords: hedonic pricing; university town; rental externalities; zoning

*This paper began as a class research project. I am grateful to the students of the 2003 Economics 3713 class for their preliminary data collection and analysis. Data collection was funded in part by a Human Resources Development Canada summer placement grant and funds provided by Acadia University.

Summary

The town of Wolfville, Nova Scotia is a small historic community, economically dominated by Acadia University. Two externalities are anecdotally considered important in Wolfville. The first externality derives from the local topography. The town is located on the north slope of a ridge, affording views of the Minas Basin, at the eastern end of the Bay of Fundy. There are a number of homes in Wolfville with a very attractive view. Popular wisdom within the town suggests that properties with a view command a higher price. The second externality is traffic noise. The southern boundary of the town is a major provincial highway, Highway 101, while the town's major traffic artery, Main Street, lies near it's northern margin. Both of these roadways are important sources of noise pollution in Wolfville. As for view properties, conventional wisdom holds that properties closer to these sources of noise sell for less.

This research project sought to measure the impact on property prices of these two externalities, the presence of a view and the level of noise pollution, using Hedonic regression. Given the geography of the town, it was seen to provide an ideal location for such an analysis. Within Wolfville there is no access to Highway 101, while Main Street is easily accessible from anywhere in town. Thus, location within the town does not determine accessibility benefits, benefits that commonly offsets noise pollution damages. Further, the undulating nature of the local geography, a consequence of the town being bisected by three creek gullies, results in view properties not being simply coincident with distance from Highway 101. These facts should provide the analysis with sufficient power to isolate the effects of both externalities on property values.

A preliminary analysis of noise pollution effects in Wolfville was conducted as an environmental economics class project in the winter of 2003. Since these results suggested sound level affected property values, a more comprehensive set of measurements were taken in the summer of 2003. At 27 sites scattered around Wolfville, a sequence of 22 one hour sound level measurements were recorded with a Larson-Davis^{TM}712 sound meter during the summer of 2003. Using polynomial interpolation, sound profiles were generated for the town using the L_{eq} (equivalent sound level) and L_{peak} (peak sound level) observations. The profiles were used to predict a sound level for the location of each property transaction between July 1998 and June 2003. Using these predicted sound levels, together with home details taken from the MLS listing information and additional observations made at the street front of each traded property, a number of hedonic regression functions were estimated. The final function explains about 90% of the variation in property values.

The presence of a view was not found to be significant in any of the regressions run. The L_{eq} observations were also not significant, while L_{peak} observations were. For the average priced home in Wolfville, an increase in the peak sound level of one decibel reduces the price by about two percent. Homes most subject to noise pollution from highway 101 are priced some ten percent below the average. When zoning classification is included in the regression, L_{peak} ceases to be statistically significant. This suggests that zoning classification segregates homes experiencing different sound levels. The highest price zoning classification is single family residential, while classifications which allow homes to have up to four apartments are the lowest priced. Since the price difference for zoning classification exceeds the sound level price differences, zoning segregation captures more than just noise level differences. As a university town with a large population of student tenants, zoning classifications also serves to separate student rental housing from the homes of non-student Wolfville residents.

The efficiency of this segregation depends on the relative impact of the relevant externalities on the occupants - whether in multiple unit or single family. If occupants of multiple unit accommodation are less willing to pay to avoid noise level damages than tenants of single family homes, then this segregation may be efficient. Likewise, if occupants of multiple unit accommodation are less sensitive to poor maintenance and neighbourhood characteristics than single family residents, then segregation may be efficient. In contrast, if being close to single family homes has beneficial spillovers for multiple family tenants, such as better enforcement of landlord maintenance responsibilities, then segregation may not be efficient. Regardless of the economic efficiency, the present pattern of zoning segregation leads to occupants of multiple family housing being subjected to higher levels of sound, and likely suffering greater neighbourhood related externalities.

1 Introduction

Wolfville is a small town, located approximately 100 kilometers west-northwest of Halifax, Nova Scotia. Its principle economic driver is Acadia University, with tourism playing an important role during the summer months. The tourist appeal of Wolfville is partly due to the many stylish and historic homes lining its main streets and its proximity to the Minas Basin, at the eastern end of the Bay of Fundy. The town itself lies on the northern slope of a low ridge, affording many homes an attractive view of the Minas Basin. However, along the southern boundary of the town, near the crest of the ridge, runs a major provincial highway, Highway 101. The location of the highway makes it a significant source of noise pollution, with traffic noise being audible north of the town site, more than one kilometer from the highway itself.

The prominent highway south of Wolfville runs to the provincial capital, Halifax. Given the proximity of Halifax, the economic hub of the provincial economy, many local residents routinely travel to the city. There is considerable political pressure to have the highway expanded from its current two lane state to a four lane divided highway. Such an expansion is expected to be beneficial to the local area, in terms of easing travel to Halifax and attracting more residents. This study was motivated by the concern that arguments about the 'twinning' project were not considering some potential adverse effects, in particular increased noise pollution.

The methodology of this analysis is Hedonic pricing, an empirical implementation of the Lancaster characteristics model of a good (Lancaster, 1966), first popularized by Rosen (1974). A residential property is seen as a bundle of characteristics. Purchasers pay attention to these characteristics - lot size, house area, type of zoning, distance from amenities, etc. when purchasing a house. They also pay attention to environmental factors such as pollution levels. This paper investigates the impact of two environmental factors, the ambient noise level and the presence of a view, on the price residential property trades for in the town of Wolfville.

Anecdotally, the adverse effect on property values of negative externalities such as noise level is well known. These anecdotes are reflected in the literature. Nelson (1982) reviews a number of studies conducted in the 1970s, a time when concern about the noise pollution effects of large infrastructure projects was mounting. In reviewing the hedonic pricing methodology used in these studies, it is pointed out that three key assumptions underlay this approach. First, it is assumed that there is sufficient turnover in the market so that buyers have the 'freedom to move' in response to difference in sound level. Second, there must be sufficient variation in sound level across the sample of houses for price impacts to be detectable. Third, it must be possible to measure sound levels at an appropriate resolution to be able to empirically estimate the relationship between property values and sound levels. The studies reviewed managed these issues to varying degrees. They find that, on average, a one decibel (dB) increase in sound levels leads to a 0.40% decline in the price of a house. A more recent review conducted for the European Commission (Navrud, 2002) surveys studies using hedonic pricing, contingent valuation, choice experiment, and conjoint analysis methods. The noise discount ranges between 0.08% and 2.30% of the property price per decibel. Since property value impacts are present values of the ongoing noise cost, it is argued that an annual or monthly impact is a more appropriate measure. For traffic noise, noise costs fall between 2 and 99 euros per decibel per household per year. Translated into Canadian dollars and assuming a discount rate of 5%, the present value noise cost is between \$62 and \$3,100.

A recent study (Wilhelmsson, 2000) considers the impact of traffic noise on the value of single family homes in Sweden. The authors consider a number of criticisms of the hedonic pricing method, including the presence of asymmetric information with respect to noise levels. If buyers are incompletely informed about noise levels, then one would expect higher turnover rates near noise sources than further away. They find no statistical evidence to support differing turnover rates, suggesting that asymmetric information with respect to noise is not an issue. They find a noise discount of 0.6% per decibel, from a log-linear model. Other important variables include house size and quality, and a housing price index. A study by Theebe (2004) uses spatial autocorrelation techniques to look for a relationship between noise levels and property values for a large sample of transactions in the Netherlands. The implied per decibel discount is around 0.4%. Some weak evidence is found for larger discounts in high income areas.

Another anecdote is that houses on busy streets sell for relatively lower prices. Hughes Jr. and Sirmans (1992) examine two suburbs of Baton Rouge, Louisiana, comparing low and high traffic neighborhoods, and also looking for a direct relationship between traffic counts and house prices, where counts are available. They find that there is a large and statistically significant negative relationship between property prices and traffic, homes on high traffic streets sell at a discount of about 8.8%. However, since they rely on traffic level itself as the variable of interest, it is unclear if traffic noise, accident risk, pollution, or some other factor related to traffic level is driving the decline in property values.

The impact of airport noise on property values has received considerable attention. A recent study by Lipscomb (2003) considers the impact of airport noise, using sound level contours reported by a local airport, on property values in a small city near Atlanta, Georgia. In contrast to many other studies, it is found that noise does not significantly affect property values. This is attributed to the unique demographic characteristics of this community, where many households have members employed in air travel related occupations. Distance from the airport therefore dominates noise as a decision variable for many purchasers.

A meta-analysis of the relationship between airport noise and property values conducted by Nelson (2004) finds an average impact on selling prices of 0.58% per decibel, with the Canadian subset of the sample generating noise discounts of between 0.8% and 0.9% per decibel. The meta-regression attempts to identify whether different methods of dealing (or failing to deal) with mobility and employment benefits of airport proximity. No difference was found among the studies, suggesting that either the positive effects of airport proximity are minimal, or that none of the studies have effectively accounted for it. The surveyed studies also seem to show a positive relationship between average property price and noise discount, with studies where the average property price is higher finding a larger discount. In so far as housing and quite are both normal goods, this is not surprising.

One method that communities use to deal with externalities is through zoning. As restrictions on land use, zoning codes can prevent activities which generate large negative externalities from locating where those externalities will be felt, and thereby protect certain land uses from these externalities. The location of commercial activities near busy roadways both facilitates access to the businesses, and separates residential property from the externalities associated with these business activities. Likewise, zoning low income housing where negative externalities are more prevalent serves to separate higher income residents from both the externalities directly related to building design and density, and any additional externalities (crime, etc.) associated with low income housing. Further, it may also reduces the cost of building low income housing by reducing the cost of acquiring the land if low income housing is located in places where other externalities are stronger.

An early empirical study (Crecine et al., 1967) considered the impact of a number of neighborhood externalities on property value for areas with different zoning classifications. For single family homes, no consistent effect of possible use externalities was found in the per unit area price. Maser et al. (1977) examine the impact of both zoning and a number of externalities on property values in Monroe County, New York. Zoning designation is not found to affect property values, while several externalities (positive near water, positive near park, negative near airport) do. The authors conclude that externalities are being appropriately priced by the market, and zoning restrictions are therefore not contributing to an outcome any different from the market outcome. Pogodzinski and Sass (1991) argue that zoning restrictions limit buyer choice and supplier offerings, and thereby impact on the pricing equation parameters. They find that interactions between zoning restrictions and specific characteristics can be significant, and that the effect of zoning restrictions estimated absent these interactions can be biased. Based on their analysis of Santa Clara County, zoning restrictions are found to significantly affect the pricing equation.

Stull (1975) examined the impact of neighborhood externalities by comparing communities within the Boston Metropolitan Area. Aerial photos were used to characterize land use in each community. The trading price of single family homes was negatively affected by increases in the proportion of most other land use types. This effect is taken as support for the contention that zoning restrictions can protect the value of single family homes. Asabere and Huffman (1997) examine the impact of hierarchical zoning on property prices in central Philadelphia. Hierarchical zoning provides a hierarchy of use, so that an area zoned for single family residential will not admit multi-family residential or commercial uses, an area zoned for multi-family residential will admit single family but not commercial uses, and an area zoned commercial will admit all three uses. It is argued that with a hierarchical system, residential property in an area zoned to allow 'lower' uses should see a price discount. Focusing on the price of apartment buildings, a discount of over 15% is found. In contrast, for Santa Clara County, California, Cervero and Duncan (2004) find a positive price premium for mixed use neighborhoods relative to single family neighborhoods. However, they argue that this may be somewhat unique, as Santa Clara is a rapidly growing area with a relative shortage of affordable housing. As a result, condominiums sell well, and single family homes in areas zoned for mixed use areas may be capturing development potential in their price.

One aspect of the exclusion afforded by zoning within the United States has been as an effective means to segregate racial groups. The price depressing effect of being in a racially heterogeneous neighborhood is commonly seen. Crecine et al. (1967) include the proportion of non-whites in their various regressions, and find that the effect of greater heterogeneity is generally negative. Maser et al. (1977) include percent "Negro" in their regressions, and find that the effect on prices is negative and significant. The results of Cervero and Duncan (2004) indicate that increasing the racial mix in a neighborhood depresses prices. Along another segregation dimension, Wang et al. (1991) examine how the proximity of rental properties, affects sale prices. They find that owner occupied homes sell for more than rented homes, that proximity to rental homes reduces price, and that the amount of rental homes in a neighborhood also reduces price. Their results are consistent with two effects, a tendency of landlords to invest less in maintenance than owner occupants, and a desire for higher income owners to segregate themselves from lower income renters. In a similar vein, Asabere and Huffman (1997) includes unemployment, and finds that homes in neighborhoods with higher unemployment rates sell for less.

As a study site for examining environmental externalities such as sound and view, Wolfville provides several attractive characteristics. As a university town with no major industrial activities, variety of land use is relatively limited. With respect to the assumptions listed by Nelson (1982), the relatively high income means that budget constraints are likely to have a limited impact on house choice, while the sound data collected shows both a relatively large range and spatial variation, with interpolation techniques developing 'reasonable' estimates for each property. The impact of noise level in Wolfville is also less likely to be confounded by access issues, as access to highway 101 is not available within the town, and no major local noise generator (excepting students) is an important employer. Incomplete information on the part of buyers - particularly new faculty moving to Wolfville from far away - may be a problem. However, highways are generally well known as noise sources, so this is unlikely to be a large issue. Further, the relatively high income makes the transactions costs associated with relocating within the town less of an issue in Wolfville, compared to other towns. Wolfville, therefore, appears to be an ideal location to measure the impact on house prices of noise pollution.

2 Data

The composition of the town of Wolfville is considerably different from the provincial averages along many demographic dimensions. Although likely important, these are not explicitly included in the analysis, as demographic data on individual buyers and sellers is not available. However, it appears to play an important part in explaining some of the results. Some key features, including income and earnings, household ownership, education, and commuting mode, are highlighted in table 1. Among those who hold down a full time job, average earnings are 15% above the provincial average. However, the median income is 11% below the provincial median. Student earnings, which are generally quite low, likely explains much of this. Home ownership is well below the provincial average, with 52% of dwellings being rented. Again, the fact that Wolfville is a university town, providing housing to students, likely accounts for much of this. Another university town effect is evident in education levels. The portion of the population with a university degree, diploma, or certificate is between two and three times the provincial average, depending on age group. Like education, the proportion of the population employed in occupations related to the university is high. Finally, work related

Table 1: Selected demographic characteristics for Wolfville, Nova Scotia. (Source: StatsCan, 2001)

	Wolfville		Nova Scotia	
	Total	Percent	Total	Percent
Population	3,658		908,007	
Median Income	16,663	89	18,735	100
Median Age	39.3		38.8	
Average Earnings	43,583	115	37,872	100
Private households	1,615	100	360,020	100
Rented dwellings	840	52	103,305	29
Owner occupied	775	48	252,150	29
Percent of pop with degree, diploma, ...				
Aged 20-34		38.7		22.8
Aged 35-44		55.6		19.6
Aged 45-64		59.0		18.1
Occupation - total	1,780	100	442,420	100
Social science, education, ...	450	25	33,375	8
Art, culture, recreation, and sport	165	9	11,125	3
Total trips to work	1,470	100	373,045	100
Trips by car, truck, or van	1,045	71	280,365	85
Walked or bicycled	365	25	33,130	9

mobility is significantly different in Wolfville, relative to the provincial average. In particular, one quarter of the working population commutes on foot or bicycle.

During the summer of 2003, a student was hired to collect sound measurements at various locations throughout the town. University employees who lived in Wolfville were asked to volunteer their yards as a site for an overnight measurement. From the volunteered properties, a subset were selected to offer a reasonably comprehensive coverage. The metering device, a Larson-Davis™Model 712 sound meter, was locked to an immovable object in the back yard of the volunteered property. The back yard was selected both for security of the recording device and to be more representative of that part of the owner's yard where noise levels were most likely to be a concern. A total of 27 sites were monitored in this way, with two extra points added to the data set, duplicating data for the one highway observation taken, and located at two other points along the highway. Figure 1 shows the location of the sound observations, relative to the major roads in the community. At each site, the data logger recorded hourly measurements for about 22 hours. From the recorded data, all intervals shorter than 3600 seconds (one hour) were dropped, as well as the observations with the two highest sound levels recorded. This was to control for contact time with the machine, which occurred when it was set up and taken down, and to allow for short duration extreme events such as heavy down-pours, lawn mowers, etc. which could skew the results.

A summary of the sound level data is reported in table 2. Sound levels are typically reported in decibels (dB). Decibels are a logarithmic measurement scale, based on the square of the sound pressure level. The measurement is normally averaged over some time interval. For this analysis, measurements are calculated as an exponential average over a one second interval,

$$\mathrm{L}_p(t) = 10\log_{10}\left[(1/T)\int_{t_s}^{t} p(\xi)^2 e^{-(t-\xi)/T} d\xi / p_0^2\right]$$

The reference level p_0 for the meter used is $20\,\mu$Pa with $t_s = t - T$ and $T = 1$ second. The peak sound level recorded is the maximum L_p measured over the recording interval, which was set to one hour. This value is designated L_{peak}. A commonly used sound level measure is the equivalent

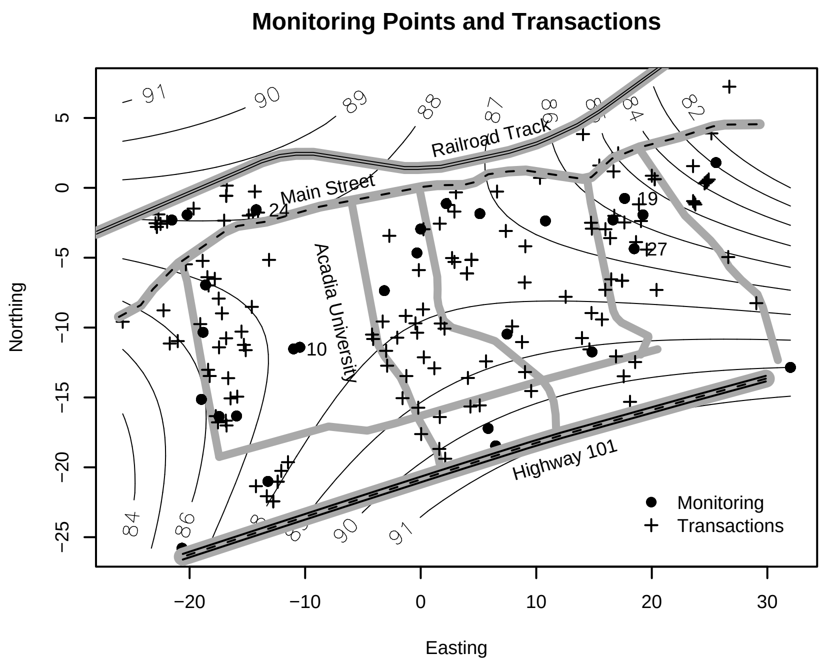

Figure 1: Map of Wolfville with sound level monitoring locations and locations of properties traded. Numbers identify monitoring sites mentioned in table 2. Contours map a quadratic interpolated of the L_{peak} sound level.

constant sound level over the recording interval. This is calculated as

$$L_{eq} = 10 \log_{10} \left[\int_{T_1}^{T_2} p(t)^2 dt / p_0^2 (T_2 - T_1) \right] \tag{1}$$

for an interval of length $T_2 - T_1$. Since sound levels are measured using a logarithmic scale, they should properly be manipulated geometrically rather than arithmetically. Alternatively, the decibel measures can be converted to a sound pressure level, and these values used for averaging and in surface interpolation. This latter approach was used in the analysis reported in this paper.

To generate sound levels for the sold properties, interpolation from the observations taken was necessary. Four different interpolation methods were tried. For sets of nearest neighbours, simple average, inverse distance weighted average, and OLS forcasting were used. Polynomial surface estimation was also applied to the entire set of sound observations. Based on explanatory power added to the hedonic regression model, and perceptions about the consistency of the graphically represented profile with local perceptions, a quadratic polynomial surface was used.

The points of interest were the locations of the properties that had been sold in Wolfville between July 1998 and June 2003. Listings data was collected with the help of a local real-estate agent. The student assistant attempted to physically locate each property, and if successful assessed the site for a number of qualitative variables not included in the listing detail - presence of a garage, paved driveway, mature trees, a view of the Minas Basin, etc. The variables measured, along with some summary statistics, are reported in table 4. A total of 149 property transactions are recorded in the dataset used. Due to missing observations in key variables, 26 of the transactions were dropped from the final analysis. Between the years 1998 and 2003, with no adjustment for inflation, the average price for a home was \$136,770. Wolfville is a historic Canadian town, which is evidenced by the fact that among the sold homes, the average age was 45.3 years, with one home of 176 years old traded.

Wolfville is also a university town, with the enrollment at Acadia university representing about half of the town's population during the university term. As such, rental accommodation is an

Table 2: Summary of sound level observations. Data was recorded at 27 sites. Two additional sites were created by selecting two points along the highway and assigning them the same observations as made at the one site that was near the highway. The No. column reports identifiers for map sites (figure 1)

Averaging	Site	No.		Mean	St. Dev.	Min.	Max.
All	Average	-	L_{eq}	47.6	6.16	35.3	67.9
			Peak	82.8	9.40	61.2	110.2
	Minimum	10	L_{eq}	41.8	2.39	38.0	46.1
			Peak	80.1	8.62	65.5	101.7
	Maximum	Hwy	L_{eq}	56.4	2.80	51.7	60.1
			Peak	89.7	5.21	82.8	102.8
Day	Average	-	L_{eq}	51.2	6.22	40.4	79.8
			Peak	87.6	9.50	65.5	113.7
	Minimum	27	L_{eq}	44.3	2.23	38.9	48.2
			Peak	78.9	7.83	71.2	99.7
	Maximum	24	L_{eq}	60.8	7.33	49.8	78.5
			Peak	88.4	11.78	78.9	129.8
Night	Average	-	L_{eq}	44.5	6.06	35.3	68.0
			Peak	78.6	9.68	61.2	111.8
	Minimum	19	L_{eq}	38.5	2.25	36.0	42.5
			Peak	76.0	4.58	70.7	80.7
	Maximum	Hwy	L_{eq}	54.2	2.36	51.7	58.7
			Peak	87.9	3.54	82.8	95.6

important component of the local real-estate market. A particularly important form that rental accommodation takes in Wolfville is large houses converted into multiple unit apartments. Within the data, the impact of rental accommodation is apparent as the presence of homes which, for listing purposes, have up to 4 full bathrooms, 5 half bathrooms, and 7 bedrooms. The importance of the rental market is also apparent in the fact that 105 of the 149 properties traded are zoned to legally allow some form of rental accommodation, and 67 were zoned in some form of multiple unit accommodation. The regression results presented below reflect both the importance that history plays in the Wolfville housing market, and the impact of the student rental accommodation.

3 Results and Discussion

As discussed in Cropper et al. (1988), it is unclear exactly what functional form a Hedonic regression function should take. Several authors have therefore used a Box-Cox transformation to evaluate whether a linear, logarithmic, or other functional form best fits the data. Figure 2 plots the likelihood function for the Box-Cox transform of the selling price as the dependent variable and a Box-Cox transformation of the square root of the selling price as the dependent variable. Independent variables were not transformed. The 95% confidence interval contains neither $\lambda = 1$ (linear) nor $\lambda = 0$ (log-linear) for the untransformed case. However, $\lambda = 0.5$ (square root) cannot be rejected. When the dependent variable is transformed and the likelihood function is again calculated, the estimated Box-Cox parameter is not significantly different from one. A fully transformed model, with the square root of the continuous independent variables included rather than their levels, generated a slightly smaller maximum likelihood value for the λ estimate on the transformed model than when λ was estimated for the model with square root applied only to the house price. Therefore, the fully transformed model is not reported.

In general, the explanatory power of all three functional forms is high. The regression diagnostics

Table 3: List of ratio scale and dummy variables, together with descriptive statistics.

Variable	Description	Mean	Median	Min	Max
SalePrice	Price at which home actually sold	136,770	123,500	28,500	399,000
Age	Age of home	45.3	25	0	176
Floor	Area of living space, in m^2	148.0	127.7	53.1	447.6
LotSize	Area of lot which house occupies, in m^2	1,119.0	958.1	0.0	12,100.0
FullBath	Number of bathrooms with a full bath	1.67	2	1	4
HalfBath	Number of bathrooms without a full bath	0.36	0	0	5
CenterDist	Straight line distance to town center, in km	0.607	0.881	0.134	1.510
MainDist	Shortest distance to Main Street, in km	0.317	0.375	0.978	0.024
AcadiaDist	Straight line distance to center of campus, in km	0.688	0.853	0.211	1.906
Bedrooms	Number of bedrooms	3.34	3	1	7
DaysListed	Number of days property on market	124.2	128.2	0	596
Leq	Measurement of average sound level, db	47.18	46.09	40.99	54.65
Peak	Measurement of peak sound level, db	87.25	87.56	79.62	90.55
WellDum	Is water source a well (well = 1)?	0.02	Town	0	1
SemiDum	Semi-detached or single family (single = 1)?	0.95	Single	0	1
Sto2Dum	One or two stories (two stories = 1)?	0.31	One	0	1
ViewDum	View of the Minas Basin (yes = 1)?	0.21	None	0	1
VHwyDum	View of the highway (yes = 1)?	0.05	None	0	1
HistDum	Is property designated historic (no = 1)?	0.02	Not	0	1
PaveDum	Is driveway paved (yes = 1)?	0.76	Paved	0	1

Table 4: List of categorical variables. In the regression, dummies are included for each possible value of categorical variable.

Name	Description	Categories				
HeatFac	Heating Source	Electric	Oil	Wood	Other	
		54	75	17	3	
ZoneFac	Zoning Classification	R-1	R-1A	R-2/4	R-8	RCDD
		44	38	39	15	13
GaraFac	Type of Garage	None	Free	Attached		
		92	21	27		
TypeFac	Single Family or Condominium	Single	Condo			
		129	20			
TreeFac	Trees	None	Young	Mature		
		25	62	53		
TitleFac	Title to Property	Freehold	LeaseHold	Other		
		127	2	20		
YearFac	Year	1998	1999	2000	2001	2002
		12	32	30	35	40
QuarFac	Quarter	Q1	Q2	Q3	Q4	
		32	54	36	27	

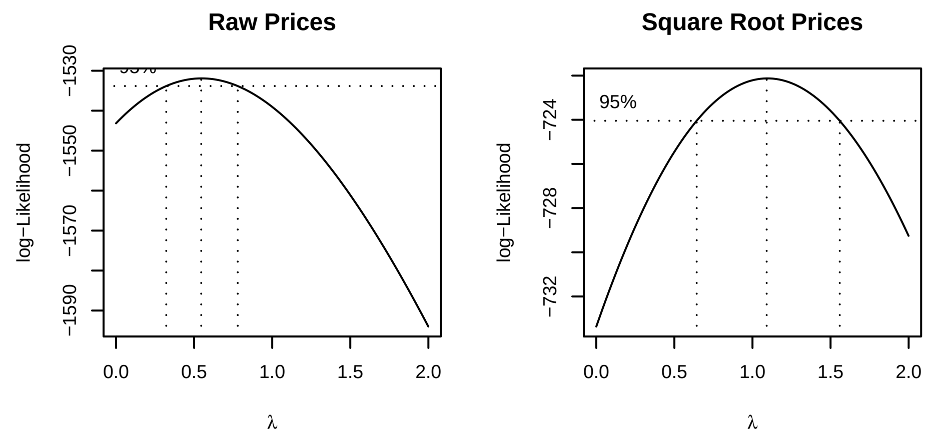

Figure 2: Likelihood as a function of λ for a Box-Cox transformation of the model.

Table 5: Regression Diagnostics

	Linear		Logarithmic		Square Root	
	no Z	with Z	no Z	with Z	no Z	with Z
R^2	0.885	0.912	0.842	0.892	0.874	0.911
F	25.830	29.235	17.952	23.223	23.235	28.683
P_F	0.000	0.000	0.000	0.000	0.000	0.000
df	94.000	90.000	94.000	90.000	94.000	90.000
Durbin-Watson	1.923	2.166	1.808	2.196	1.871	2.208
P_{DW}	0.200	0.640	0.069	0.701	0.129	0.725
Breusch-Pagen	25.098	39.757	28.054	53.495	23.469	56.834
P_{BP}	0.623	0.163	0.462	0.010	0.709	0.004
Moran's I	−0.004	−0.019	0.002	−0.016	−0.001	−0.018
P_I	0.535	0.069	0.101	0.175	0.235	0.088

are reported in table 5, for two regressions of each functional form. When zoning is not include, the R^2 values range between 0.842 and 0.885. With zoning classifications included, the R^2 values range from 0.892 to 0.912. As a check for specification errors, the Durbin-Watson statistic is reported. It's values do not suggest a problem. The Breusch-Pagen test for heteroscedasticity is significant for the log-lin and square root-lin versions of the model when zoning is included, but insignificant for the others. For completeness, White's (1980) heteroscedasticity corrected covariance estimated P values are reported as well as the the conventionally calculated P values in the regression results below. The residuals were also tested for spatial correlation by calculating Moran's I statistic (Moran, 1948; Anselin, 1988; Anselin and Bera, 1998), a spatial analog to the Durbin-Watson statistic. The reported result uses a weighting matrix with inverse neighbor distances as weights, for all neighbors. Square root and squared inverse distances were also tried, as well as restricting the set of neighbors to those within smaller radii. For none of these was significance found at the five percent level.

Given the Box-Cox results, only estimates for the square root of selling price regressions are reported (table 6). A number of different dependent variables were considered, and stepwise regression methods were explored to identify variables which made the largest contributions. However, the theoretical interplay between some of the key variables, particularly sound level and zoning classification, meant that exclusive reliance on stepwise results could mask important relationships. Thus, the final model included all variables that theoretical reflection suggest are important, in preference to those selected by the stepwise procedure.

The variables included in the regressions fall into three general categories: household characteristics, neighbourhood or amenity values, and nuisance variables. Household characteristics include age, floor space, lot size, number of bathrooms with a full bath, number of bathrooms without a full bath, number of bedrooms, household water supplied by a well, source of heat (electric, oil, wood, or other), and if the property has been designated as historic. Age, water source, and historic designation are expected to affect selling price negatively. Age as older homes are more costly (heating, etc.) to occupy and maintain, water source as operating costs of a well exceeds costs of supply from the town, and historic as restrictions are put on modifications to the property. The remaining household characteristics are expected to be positive. Most of these signs are self-evident. In the case of heat source, the comparison case is electric, which during the study period was the most costly method of heating a home. In all cases, quadratic terms are expected to have the opposite sign to their linear complement, reflecting a diminishing marginal effect.

Taxes and assessed value have not been included. As this regression focuses on one town, the tax rate is constant throughout the town. We would therefore expect the tax bill to explain most of the variation in price, to the extent that the variation is captured by assessed value. To the extent that assessed value accurately tracks the true value of homes in Wolfville, it is endogenous. Thus, beyond lack of tax rate variation, tax bills themselves would also be endogenous.

Neighbourhood characteristics include distance to center of town, distance to center of Acadia campus, perpendicular distance from Main Street, presence of a clear view, presence of an obstructed view, peak sound level, as taken from estimated sound profile, and dummy variables for zoning classification. The distance variables are all expected to be negative, as these are important destinations. Presence of a view is expected to be positive, with a clear view generating a larger impact than an obstructed view. Peak sound level is expected to be negative, with its square positive. Finally, from a naive perspective, zoning codes are expected to be positive, as they provide the owner additional revenue generating opportunities. However, the reviewed research suggests that zoning serves as a segregation tool and a method of isolating externalties. To the extent that this effect is taking place, zoning code dummies may be negative.

Finally, dummy variables for year and quarter are included. These are considered nuisance variables, as their presence complicates the regression, but their values are not the main focus.

Most of the regression results are consistent with expectations. In all cases where quadratic terms are added, the expected diminishing effect is present. Among household characteristics, age and floor space, together with the number of full bath bathrooms stand out particularly strongly. Somewhat less strong in terms of P value are the size of the lot and the number of half bathrooms. In particular, these variables loose significance at $\alpha = 0.05$ when the HCCM adjustment is made. Among variables significant at $\alpha = 0.10$, the 'other' heat source stands out. There are only a few observations in this category, with one being a geothermal heat exchange unit. This equipment can substantially reduce heating costs. The historic dummy is also significant at $\alpha = 0.10$, and this variable has a sign opposite to that expected. Since Wolfville is widely known as a historic community, perhaps those choosing to purchase property in Wolfville value this characteristic, in spite of the restrictions imposed on maintenance and renovation. Of the remaining variables, well has the expected sign while bedrooms does not. Although the P value suggests that this parameter estimate has little explanatory power, one possible explanation follows from the fact that floor space has been controlled for. As such, adding a bedroom to a home without changing the floor space will reduce the size of all other rooms in the house.

Among the neighbourhood characteristics, to Acadia and to Main Street have the expected signs. Zoning classifications are significant and negative for three of the four category dummy variables. The signs suggests that zoning is serving to protect the value of single family homes from adverse impacts more common where multiple family homes are permitted. The fact that sound level becomes insignificant when zoning is included suggests that zoning is grouping homes into categories experiencing with similar noise levels. When sound level is significant, the parameter signs are opposite to expectations. However, since the average value of L_{peak} is above 80 dB, the marginal impact at the mean is as expected. These marginal impacts are reported below. Finally, the distance to the center of town has no impact on property values, both in terms of the magnitude

Table 6: Hedonic regression results, with square root of selling price as dependent variable. Results are presented for regressions with and without zoning classifications. P_{Tr} significance levels are calculated using traditional standard errors, while P_H are calculated using standard errors from a heteroskedasticity corrected covariance matrix (HCCM).

	With Zoning			Without Zoning		
Factor	β	P_{Tr}	P_H	β	P_{Tr}	P_H
(Intercept)	−421.230	0.941	0.485	−11843.983	0.039	0.062
Age	−1.029	0.000	0.015	−1.284	0.000	0.008
Age^2	0.008	0.001	0.041	0.008	0.001	0.055
Floor (m^2)	1.113	0.000	0.009	1.076	0.000	0.008
Floor^2 (m^2)	-0.001	0.004	0.110	-0.001	0.008	0.103
Lot (m^2)	0.026	0.012	0.100	0.019	0.003	0.250
Lot^2 (m^2)	-0.000	0.420	0.445	-0.000	0.124	0.459
Full Baths	31.317	0.000	0.000	37.140	0.000	0.000
Half Baths	18.561	0.004	0.121	22.111	0.003	0.066
Bedrooms	−2.811	0.490	0.311	−2.107	0.647	0.361
Well	−5.838	0.795	0.384	−31.878	0.212	0.072
Heat: Oil	6.079	0.485	0.297	14.554	0.126	0.127
Heat: Other	43.609	0.072	0.325	36.692	0.187	0.330
Heat: Wood	3.661	0.757	0.405	16.186	0.211	0.147
Historic	46.487	0.070	0.296	51.780	0.079	0.255
to town center (km)	0.002	0.628	0.352	0.003	0.456	0.293
to Acadia (km)	−1.328	0.015	0.022	−1.249	0.038	0.049
to Main Street (km)	−3.421	0.005	0.007	−2.082	0.065	0.051
Clear view	−5.839	0.507	0.331	−2.294	0.818	0.433
Obstructed view	−13.465	0.077	0.073	−10.528	0.227	0.154
Peak (dB)	8.551	0.949	0.487	279.518	0.037	0.059
Peak^2 (dB)	−0.008	0.992	0.498	−1.621	0.037	0.059
Zone: R-1A	−26.034	0.007	0.023			
Zone: R-2/4	−58.668	0.000	0.000			
Zone: R-8	−14.244	0.566	0.310			
Zone: RCDD	−57.010	0.009	0.002			
Year: 1999	14.105	0.264	0.167	19.056	0.193	0.154
Year: 2000	30.035	0.014	0.008	37.184	0.009	0.010
Year: 2001	50.444	0.000	0.000	59.134	0.000	0.001
Year: 2002	50.210	0.000	0.002	59.300	0.000	0.002
Quarter: Q2	7.415	0.416	0.245	6.042	0.564	0.318
Quarter: Q3	1.768	0.852	0.443	0.559	0.959	0.483
Quarter: Q4	10.100	0.376	0.278	2.108	0.870	0.453

Table 7: Dollar and percentage impact of a unit change in selected regressors. The comparison house has the average values for ratio scale variables. It is supplied with town water, has electric heat, does not have a view, and was sold in the first quarter of 2000. For the regression with zoning, it was also a single family residential zoned home.

	Without Zoning		With Zoning	
Factor	$\Delta Price$	$\Delta\%$	$\Delta Price$	$\Delta\%$
Age	−469.75	−0.4	−513.24	−0.3
Floor (m^2)	483.30	0.0	517.16	0.0
Lot (m^2)	15.92	0.0	17.39	0.0
Full Baths	26,630.37	20.7	29,095.79	19.0
Half Baths	15,854.17	12.3	17,321.94	11.3
Bedrooms	−1,510.87	−1.2	−1,650.74	−1.1
Well	−21,840.91	−17.0	−4,539.19	−3.0
Heat: Oil	10,647.61	8.3	4,799.25	3.1
Heat: Wood	11,868.06	9.2	2,881.71	1.9
Heat: Other	27,655.59	21.5	36,065.30	23.5
Historic	39,808.61	31.0	38,579.43	25.1
to town center (km)	1.95	0.0	2.13	0.0
to Acadia (km)	−895.50	−0.7	−978.40	−0.6
to Main Street (km)	−1,493.05	−1.2	−1,631.27	−1.1
Peak (dB)	−2,618.05	−2.0	−2,860.43	−1.9
Zone: R-1A			−19,717.19	−12.9
Zone: R-2/4			−42,518.50	−27.7
Zone: R-8			−10,956.21	−7.1
Zone: RCDD			−41,411.97	−27.0

of the parameter estimate and in terms of its statistical significance. The type of view also fails to be significant at $\alpha = 0.05$, and its sign is the opposite of expectation. No clear interpretation for this result is offered.

For the nuisance variables, the year and quarter dummy variables capture effects as expected. Over time, the average price at which Wolfville homes sell is increasing. Also, relative to the first quarter (January to March), home prices in the other quarters are higher. The common wisdom holds that it is best to sell in the spring. From the results, spring prices are higher than winter and summer prices. However, fall prices are highest. Again, as these estimates are far from significant, little weight is put on them.

Table 7 reports the dollar price change and relative price change for the average house traded in Wolfville, for the square root sale price regressions. The average house, which is almost 50 years old, suffers a price discount of about $500 for an additional year of age. This discount is declining, and becomes positive at around 80 years of age. An additional square meter of floor space increases the price by about $500. This is approximately half the area cost for new construction. An additional square meter of lot size adds less than $20 to the price of a home. An additional full bathroom adds around 20% to the price of the average home, all other things equal, and an additional half bathroom adds about 12% to the price. An additional bedroom reduces the price of an average home by a little over one percent. The price impacts for water source and heat source fluctuate substantially in response to whether or not zoning is included in the regression. Using the midpoint of the estimates, the present value benefit of having wood or oil heat is about $7,000. If the relevant discount rate is 5%, then the house price impact implies that these heat sources save about $350 per year, and if the relevant discount rate is 10%, then they save about $700 per year. This is loosely consistent with anecdotal evidence. The final home characteristic is historic designation, which increases the price by almost $40,000.

Among neighbourhood characteristics, the distance to the town center has a small positive effect. The average home buyer pays about two dollars to be an extra kilometer away from the town center. In contrast, the average buyer pays almost $1,000 to be a kilometer closer to Acadia university, and around $1,500 to be a kilometer closer to Main Street. One kilometer is approximately the width of the town, and moving one kilometer away from Main Street represents an elevation gain of more than 50 meters. Since about one quarter of Wolfville residents bicycle or walk to work, this hill may represent an important decision in home location choice. A one decibel increase in peak sound level decreases the price of the average house by about $2,700, a little under two percent of the price. This is in the range reported by other studies. In so far as quiet is a normal good, and the average income of Wolfville home purchasers is high, it seems reasonable that the price discount is in the upper range of values reported in other studies. Finally, the impact of zoning classification stands out particularly strong. Properties zoned R-1A allow one rental suite, R-2/4 allows up to four apartments in a house, R-8 allows up to eight apartments, and RCDD is a general development category, residential comprehensive development district. The difference between R-2/4 and R-1, more than $40,000, is greater than the price difference observed between the loudest and most quite parts of Wolfville, about 15%. In so far as zoning is segregating based on externalities, the segregation is capturing more than sound level effects.

Given that the sound level discount is not adequate to explain the zoning code pricing impact, this impact likely reflects other characteristics of the Wolfville housing market. As discussed above, one of these is the importance of student rental accommodation. This rental market has created a pattern of zoning which places a concentration of multiple unit housing in the neighborhood of the university campus. In so far as home buyers do not desire living with university students as neighbors (externality effects such as loud parties, fears about behaviors children may be exposed to, etc.), demand is likely lower for homes near the university which are zoned for multiple units. This fact may be compounded by renovation costs. Many multiple unit houses are larger single family homes which have been converted into suites. Anyone purchasing such a property for use as a family home would face significant renovation costs. These buyers would therefore not be willing to pay as high a price for many of the R-2/4 or R-8 zoned homes, as for an R-1 zoned home which requires little or no modification. The R-1A effect is surprising, as such a house is unlikely to require much modification. However, since the owner of a house can always rent it to a group of students, proximity to the university may be a key variable as well in determining the presence of rental housing related externalities.

A key question is whether zoning in Wolfville is welfare improving. Ohls et al. (1974) describe two purposes for zoning restrictions. Externality zoning is land use restrictions to minimize the impact of externalities. Such zoning can be Pareto improving. Fiscal zoning restrictions are manage property use to achieve a fiscal objective such as minimizing tax rates. Courant (1976) uses a general equilibrium model of a metropolitan area, based on the work of Ohls et al., to show that fiscal zoning can only increase property prices and thereby reduce consumer welfare. Whether or not zoning practices are welfare improving for Wolfville depends on the size of externalities associated with rental (principally student) housing and the cost of other methods of controlling those externalities. Other methods of controlling these externalities include noise and litter regulations and maintenance standards. Enforcement of tenant behavior is likely difficult with transitory tenants such as students, so that using such regulations is likely to increase landlord costs. To the extent that landlords have disproportionate political power - not unlikely in a community with such a high portion of renting residents - zoning regulations will be the preferred instrument.

A key question in analyzing the efficiency of zoning is how the externalities affect the involved parties. In general, the argument is that owner-occupied properties are negatively affected by being adjacent to renter occupied properties. Renters, or their landlords, are less likely to maintain the rented property to the same standard as an owner-occupier would. This generates a negative externality to the owner-occupier neighbour. A question seldom discussed is whether the owner-occupier generates a positive externality for the renter. Two mechanisms may exist for such an effect. First, the renter may enjoy viewing the well maintained homes and yards of nearby owner-occupiers. Second, neighbouring owner-occupiers may demand a higher standard of their renter neighbours and/or their landlords than would be expected if the neighbour is another rental property. If these positive externalities exist, then the efficient zoning pattern may involve many small zones rather than a small number of large zoning categories.

As pointed out by Pogodzinski and Sass (1991), it may be unreasonable to assume that shift parameters are sufficient to capture the impact of zoning on the pricing equation. Regressions were therefore run interacting the zoning classification with a number of continuous regressors - age, living space, lot size, distance to Acadia, etc. Stepwise regressions retained a number of these interacted variables. However, the individual parameter estimates were far from significant. This suggests that the pricing equation likely does differ between zoning types. However, multicollinearity and/or small sample size preclude accurate estimation of this effect. Further, since both the signs and magnitudes of the parameter estimates did not change substantially, results for the interaction terms are not reported.

Several variables, such as type of ownership (freehold vs leasehold), style of house (semi-detached or detached), type of house (single family or condominium), etc. were included in the initial models as dummy variables. None of the dummies generated significant coefficients, and all were dropped through the stepwise process. It can be argued that different ownership types, house styles, or house types may generate different pricing functions. The data set was not large enough to allow a model with this diversity of effects to be estimated. To limit potentially confounding factors, final results were estimated without including condominiums or any properties where the title was not freehold.

With respect to the possible twinning of Highway 101, this study suggests that peak sound events, such as passing tractor-trailer units, are reflected in property prices. If twinning increases traffic speed, then peak sound levels will also increase. If 300 homes, about one quarter of the homes in Wolfville, experience an average sound level increase of one decibel, the total damage cost is about $810,000. This amount needs to be compared to the cost of measures to reduce noise pollution associated with the highway expansion.

The results of this analysis suggest that the most important externalities affecting Wolfville property values relate to student housing. Whether zoning large tracts near the university for multi-family residential is the most efficient method to manage this externality is not clear. This approach has the apparent advantage of placing the burden of the externality on those that generate it, the students. However, to the extent that the externality is generated by landlords who are able to invest relatively little in maintenance, this advantage may be illusory. Student ghettos permit landlords to minimize maintenance as the tenants are highly transitory and unfamiliar with their rights. If student housing was in mixed use neighborhoods, pressure on landlords to maintain their properties would likely be higher. If this pressure is sufficient to raise the maintenance standard enough, then the welfare of resident-owners need not be adversely affected, while the welfare of student tenants will increase. The results of this research clearly indicate that further work is needed in this area.

4 Conclusion

The results of the analysis reported in this paper suggest that many of the factors affecting property values in Wolfville, Nova Scotia, are the same as those found elsewhere. In particular, property values are increasing in the area of the house, the area of the lot, and the number of bathrooms. Of the two externalities measured - sound levels and the presence of a view, only peak sound level was found to be significant. At the average house price, a one decibel increase in peak sound levels reduces the house price by just under two percent. Two interesting results stand out. First, the impact house age has on price is not that large, and reaches the maximum discount at about eighty years. Further, there is a positive premium attached to historic properties. Purchasers in Wolfville appear willing to pay a premium for older homes. Second, there is a strong negative effect of zoning designations that allow rental accommodation. Since Wolfville is a university town, this is likely due to a 'student ghetto' effect. Given the unique nature of university towns - a disproportionately large number of residents who are both highly transient and unfamiliar with tenant rights - further work is needed to establish whether zoning that accommodates student ghettos is welfare improving.

References

Anselin, L., 1988. Spatial Econometrics: Methods and Models. Kluwer Academic Publishers.

Anselin, L., Bera, A. K., 1998. Spatial dependence in linear regression models with and introduction to spatial econometrics. In: Ullah, A., Giles, D. (Eds.), Handbook of Applied Economic Statistics. Marcel Dekker, Ch. 7, pp. 237–289.

Asabere, P. K., Huffman, F. E., 1997. Heirarchical zoning, incompatible uses and price discounts. Real Estate Economics 25 (3), 439–451.

Cervero, R., Duncan, M., 2004. Neighbourhood composition and residential land prices: Does exclusion rais or lower values? Urban Studies 41 (2), 299–315.

Courant, P. N., 1976. On the effect of fiscal zoning on land and housing values. Journal of Urban Economics 3 (1), 88–94.

Crecine, J. P., Davis, O. A., Jackson, J. E., 1967. Urban property markets: Some empirical results and their implications for municipal zoning. Journal of Law and Economics 10, 79–99.

Cropper, M. L., Deck, L. B., McConnel, K. E., 1988. On the choice of functional form for hedonic price functions. The Review of Economics and Statistics 70 (4), 668–675.

Hughes Jr., W. T., Sirmans, C. F., 1992. Traffic externalities and single family house prices. Journal of Regional Science 32 (4), 487–500.

Lancaster, K. J., 1966. A new approach to consumer theory. The Journal of Political Economy 74 (2), 132–157.

Lipscomb, C., 2003. Small cities matter, too: The impacts of an airport and local infrastructure on housing prices in a small urban city. Review of Urban & Regional Development Studies 15 (3), 255–273.

Maser, S. M., Rosett, R. N., Riker, W. H., 1977. The effects of zoning and externalities on the price of land: An empirical analysis of monroe county, new york. Journal of Law and Economics 20, 111–132.

Moran, P., 1948. The interpretation of statistical maps. Journal of the Royal Statistical Society B 10, 243–51.

Navrud, S., 2002. The state-of-the-art on economic valuation of noise. Tech. rep., European Commission DG Environment.

Nelson, J. P., May 1982. Highway noise and property values. Journal of Transport Economics and Policy 16 (2), 117–138.

Nelson, J. P., 2004. Meta-analysis of airport noise and hedonic property values: Problems and prospects. Journal of Transport Economics and Policy 38 (1), 1–28.

Ohls, J. C., Weisberg, R. C., White, M. J., 1974. The effect of zoning on land value. Journal of Urban Economics 1 (4), 428–444.

Pogodzinski, J., Sass, T. R., 1991. Zoning and hedonic housing price models. Journal of Housing Economics 1 (3), 271–292.

Rosen, S., 1974. Hedonic prices and implicit markets: product differentiation in pure competition. Journal of Political Economy 82, 34–55.

StatsCan, 2001. Statistics canada community profiles. http://www.statscan.ca/.

Stull, W. J., 1975. Community environment, zoning, and the market value of single-family homes. Journal of Law and Economics 18 (2), 535–557.

Theebe, M. A. J., 2004. Planes, trains, and automobiles: The impact of traffic noise on house prices. Journal of Real Estate and Economics 28 (2/3), 209–234.

Wang, K., Grissom, T. V., Webb, J. R., Spellman, L., 1991. The impact of rental properties on the value of single-family residences. Journal of Urban Economics 30 (2), 152–166.

White, H., 1980. A heterskedastic consistent covariance matrix estimator and a direct test of heteroskedasticity. Econometrica 48, 817–838.

Wilhelmsson, M., 2000. The impact of traffic noise on the values of single-family houses. Journal of Environmental Planning and Management 43 (6), 799–815.

A Alternative Surface Generation Methods

With 27 noise level observation sites distributed unevenly around Wolfville, it was necessary to project from these locations to the properties that traded. Four different methods were used: (1) simple average, (2) distance weighted average, (3) spatial OLS forecast, and (4) polynomial surface generation.

Simple Average The simple average was calculated as

$$\overline{L}_i = 10\log_{10}\left\{\frac{1}{\sum_{j\in N_i(n)}\#T_j}\sum_{j\in N_i(n)}\left[\sum_{k\in T_j}\left(10^{L_{jk}/10}\right)^{1/2}\right]\right\}^2 \tag{2}$$

where $N_i(n)$ is a set indexing the n nearest neighbor measurement sites of sold property i, T_j is a set indexing the observations made at site j, L_{jk} is the decibel sound level measured at site j, observation k, and $\#T_j$ is the number of elements in set T_j.

Distance Weighted Average The distance weighted average was calculated as

$$\overline{L}_i = 10\log_{10}\left\{\sum_{j\in N_i(n)} w_j\left[\sum_{k\in T_j}\left(10^{L_{jk}/10}\right)^{1/2}\right]\right\}^2 \tag{3}$$

with

$$w_j = \frac{\#T_j d_{ij}}{\sum_{k\in N_i(n)}\#T_k d_{ik}} \tag{4}$$

where d_{ij} is the distance between observation site j and sold property i.

Spatial OLS Forecast To generate a surface using this method, a vector of sound pressure levels P was formed with all the sound level observations for the $N_i(n)$ nearest neighbor observation sites, where $p_{jk} = \left(10^{L_{jk}/10}\right)^{1/2}$. This vector was then regressed on an intercept and vectors X and Y containing the coordinates of the observations in P, as

$$P = \beta_0 + \beta_X X + \beta_Y Y + U \tag{5}$$

where U is a disturbance vector. The sound level at sold property i was then forecast as

$$\overline{L}_i = 10\log_{10}\left(\hat{\beta}_0 + \hat{\beta}_X x_i + \hat{\beta}_Y y_i\right)^2 \tag{6}$$

where x_i and y_i are the coordinates of sold property i.

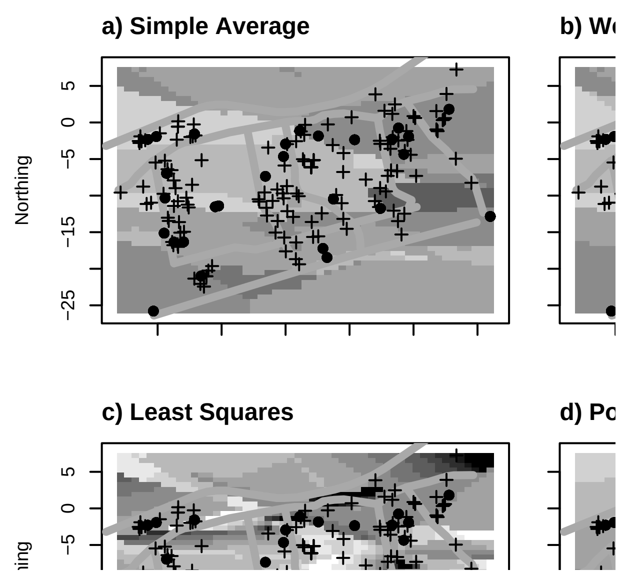

Figure 3: Wolfville sound level profiles generated using four different interpolation methods and peak sound level observations. Neighbor based methods (a, b, and c) use 6 neighbors. Polynomial surface is second order. Darker colors correspond to a lower sound level.

Polynomial Surface Generation To generate this surface, a polynomial regression was run using all of the sound observations. The individual observations were transformed to sound pressure values as above, and then a regression was run as

$$P = \beta_0 + \beta_X X + \beta_Y Y + \beta_{XX} X^2 + \beta_{XY} XY + \beta_{YY} Y^2 + \ldots + U \tag{7}$$

for various polynomial orders. The decibel sound level at any site is then forecast according to

$$\overline{L}_i = 10 \log_{10} \left(\hat{\beta}_0 + \hat{\beta}_X x_i + \hat{\beta}_Y y_i + \hat{\beta}_{XX} x_i^2 + \hat{\beta}_{XY} x_i y_i + \ldots \right) \tag{8}$$

where x_i and y_i are the coordinates of the sold property i.

An example of the sound profiles generated by an implementation of each of the methods is shown in figure 3. Each of the methods that uses nearest neighbors is implemented using the six nearest neighbors. The polynomial surface is generated using a second order (quadratic) polynomial. The greatest heterogeneity in sound levels occurs for the OLS projections. The averaging methods, simple and weighted, are less heterogeneous than the OLS approach, but not as smooth as the polynomial surface. Given the topography of the town, known locations of sound barriers, along the highway, and anecdotal evidence about which parts of town are most quiet, the polynomial surface has the best 'fit'. It is therefore used for the balance of the analyses reported in the body of the paper.