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The impact of oil and natural gas facilities on rural residential property values: a spatial hedonic analysis

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Abstract

This paper examines the impact of oil and gas facilities on rural residential property values using data from Central Alberta, Canada. The influences are evaluated using two groups of variables characterizing hazard effects and amenity effects. A spatial error model was employed to capture the spatial dependence between neighbouring properties. The results show that property values are negatively correlated with the number of sour gas wells and flaring oil batteries within 4 km of the property. Indices reflecting health hazards associated with potential rates of H_2S release (based on information from Emergency Response Plans and Zones) also have a significant negative association with property prices. The findings suggest that oil and sour gas facilities located within 4 km of rural residential properties significantly affect their sale price.

JEL classification: Q32; Q49

Keywords: Sour gas; Hedonic prices; Property value impacts

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1. Introduction

The oil and gas sector is large, important and ubiquitous in the Alberta economy. In particular, the natural gas sector has grown in importance with production doubling since the mid-1980s. Almost a third of the natural gas output is ''sour'' gas; that is, contains levels of hydrogen sulphide (H_2S) that imposes potential health risks. Because, with the exception of the tar sands, oil and gas activity is concentrated in the populated regions of the province, the industry must co-exist with other industries, largely agriculture, and with neighbouring communities. Amenity and, in the case of sour gas, health and safety considerations are often concerns of those located near industry facilities. The expansion of natural gas production has heightened those concerns. Surprisingly, relatively little is known of the impacts of industry proximity. For example, examinations into the health implications of long-term exposure to low-level H_2S are ongoing. Also, unlike for many other activities (e.g., airports, power plants and lines, hog operations, air pollution, schools and parks), investigations into the impact of oil and gas industry activity on the values of neighbouring properties seem rare. The purpose of this study is to contribute towards correcting this deficiency by studying the effects of the presence of sour gas and other oil and gas facilities on the values of rural residential properties in the vicinity of the City of Calgary, Alberta.

The paper begins with a section elaborating upon the industry–community interface and the risks associated with sour gas. The data employed in this study are then reviewed. The fourth section outlines the hedonic model and the spatial econometric analysis. This part is followed by presentation and discussion of the empirical results. A brief conclusion completes the paper.

2. The industry–community interface

2.1. Scope of the sector

The oil and gas sector in Alberta represents a major component of the provincial economy. Although the contribution in any year varies considerably with prices, the oil and natural gas industry (exploration, production, transport and processing) represents 20–25 percent of provincial output and contributes a similar share to provincial government revenues directly in the form of royalties and lease revenues from Crown-owned resources. Alberta currently supplies about 12% of the natural gas consumption in the US, over 50% of Canadian consumption, and gas is an input into a provincial petrochemical industry servicing domestic and export markets. The industry has become important and has grown rapidly over the last 50 years. This expansion has been paralleled by a substantial growth in the Alberta population, particularly in and around the urban centres in the province. The rapid expansion of the oil and gas sector (both primary and downstream processing and manufacturing), the expanding urban regions, and the importance of agriculture to the provincial economy has set the stage for conflict between the oil and gas industry and rural residents.

2.2. Sour gas and associated concerns

Although disagreements involve a number of issues, a major concern in the province is the production of sour gas. Sour gas is a natural gas that contains hydrogen sulphide, a colourless flammable compound that has an unpleasant smell similar to that emitted by rotten eggs and that is hazardous to humans and animals in relatively low concentrations.[1] Gas containing at least 1% H_2S is considered "sour" and gas with less than 1% H_2S is considered "sweet." While some H_2S can be released due to accidents and equipment failures at sour gas facilities, the industry converts about 97% of the H_2S in the gas to elemental sulphur that is used in the manufacturing of fertilisers, pharmaceuticals, plastics and other products (Petroleum Communication Foundation, 2000). The remaining H_2S is usually burned in flares or incinerators that results in the conversion of H_2S to sulphur dioxide (SO_2), small quantities of other toxic compounds such as carbonyl sulphide (COS) and carbon disulphide (CS_2), nitrogen oxides (NOx) and volatile organic compounds (VOCs).

The production of sour gas has naturally led to concerns over the health effects of the various compounds found in the gas, as well as general air and water quality (Marr-Laing and Severson-Baker, 1999). These concerns have been expressed in various public forums and in public advisory groups established by the industry and government to address and study them (Provincial Advisory Committee on Public Safety and Sour Gas, 2000; Nikiforuk, 2002a). The scientific studies conducted in the province to date have neither found adverse effects of emissions on lakes or rivers, nor have researchers found convincing evidence of impacts of low levels of exposure to H_2S on the health of humans or livestock. This is, however, a topic of ongoing research. Despite the limited evidence, some people hold strong opinions about possible negative effects and, in a few cases, there have been widely publicized conflicts between the industry and persons neighbouring sour gas facilities (Nikiforuk, 2002a, 2002b). While sour gas occurrences have diminished in recent years due to increased care and regulation, there has been several larger scale sour gas events involving well blow-outs or uncontrolled releases in the province and fatal accidents involving industry workers overcome by H_2S. However, there have been no casualties among the general public.

About 30% of Alberta's natural gas production is sour gas and much of that is found near populated areas (Nikiforuk, 2002a). Furthermore, the rising demand for natural gas has expanded its exploration and production and has increased the number of Alberta residents facing actual or proposed sour gas developments in their communities. Naturally, residents neighbouring proposed and existing sour gas developments are concerned about the possible health risks and other potential negative impacts. It is expected that those concerns may have a negative effect on property values. This paper examines the impacts of sour

[1] H_2S can be detected by the human olfactory system in concentrations of 0.01–0.03 ppm. Levels of 1–5 ppm can cause nausea and headaches; concentrations of 50–250 ppm result in olfactory paralysis; and imminent threat to life can occur when concentrations reach 300–500 ppm (Gephart, 1997). The human olfactory system is deadened with concentrations above 100 ppm, giving a false sense of security that no danger is present (Marr-Laing and Severson-Baker, 1999).

natural gas facilities, and of other oil and gas developments, on property values of residential acreages in selected areas around the City of Calgary, Alberta.

Health and safety risks are a clear concern associated with sour gas facilities because they represent a special hazard. This situation is recognized to an extent in regulations requiring minimum setback distances between sour gas and oil facilities and the nearest residence, business, or occupied area (such as campgrounds and recreational areas). The setback distance varies according to the level of the hazard represented by the facility. In addition to setbacks, emergency plan response zones (EPZs) are established around all facilities that have the potential to affect public safety. For sour natural gas facilities, the size of these zones can range up to several kilometres and the size is related to the maximum potential volumes or rates of release of gas. In conjunction with these zones, emergency response plans (ERPs) are established to determine the procedures to notify the relevant members of the affected public in the event of an emergency. The industry is required to conduct regular tests of their emergency response, which includes routine contact with residents living within an EPZ. Also, upon the sale of property within one or more EPZs, the seller is required to inform the buyer of the EPZs affecting the property. Thus, one can expect property values to reflect health and safety considerations.

The presence of industry infrastructure and associated activities may also adversely impact nearby property values for amenity reasons. Industrial structures and activities on what landowners may perceive as natural landscapes can detract from enjoyment of property. Many acreage owners choose to live in rural areas to escape urban and industrial development. Even though regulations require that the land affected by oil and gas wells must be restored to at least the equivalent of its previous condition, a typical well in Alberta exists and produces for about 20 years. In addition, other types of facilities such as pipelines, pumping stations, gas processing plants and oil batteries are typically associated with wells. The presence of such facilities near acreages may further reduce enjoyment of these properties and, thus, could negatively affect their values.

2.3. Assessing the implications for property values

Despite the importance of this issue in Alberta, and likely also in similarly developed jurisdictions in the USA, there have been few studies that examine the effects of oil and gas production facilities on property prices although there are obvious potential hazard and amenity implications. We are aware of only three (all consultant reports commissioned by oil companies operating in Alberta). Those reported little to no impacts of infrastructure on prices of (Deloitte et al., 1988; Lore and Associates Ltd., 1988; Serecon, 1997). The methods employed in these studies, however, have not been the typical techniques employed by economists examining the impacts of environmental amenities and health risks on property values. These studies grouped relatively small samples of properties according to their proximity to infrastructure and compared prices across these groupings (or in pairs of similar properties), or used price regression that included few property or industry variables.

The principle technique used by economists to examine such impacts has been hedonic price analysis (Taylor, 2003). Examples of studies that have uncovered reasonably large effects on residential land prices include the transport of hazardous wastes (Gawande and

Jenkins-Smith, 2001), electricity transmission lines, (Hamilton and Schwann, 1995) changes in water quality (Leggett and Bockstael, 2000) and hog operations (Palmquist et al., 1997). The single hedonic study we uncovered on the effects of oil and gas infrastructure on prices is by Flower and Ragas (1994) who examined the influence of large-scale oil and gas infrastructure in the form of refineries on residential property prices.

This paper reports efforts to determine the impact of proximity to small to medium oil and gas production facilities on rural residential property values. To the extent our data permit, efforts were made to assess the effects of both hazard and amenity considerations. Spatial hedonic methods were explored and ultimately used in this analysis.

3. The data

The data come from areas having significant sour gas activity near the City of Calgary, a city of approximately one million residents in southern Alberta, Canada. The shaded areas in Fig. 1 show the townships comprising the study area. A township is a 6-mile $\times$ 6-mile block. Thirty full townships and parts of six other are included. Oil and gas facilities in the selected townships ranged from sparse to dense. The area spans three rural jurisdictions—the Municipal Districts of Rocky View and Foothills, and Mountain View County.[2] Arm's length sales of ''country residential'' properties in this area during the period January 1994 (when data in electronic form became available) to March 2001 were analyzed.

The initial sample contained information on the sale of 612 residential properties that ranged in size from 1 to 40 acres. The acreage limitation essentially ensured that the property was rural but also residential in that it did not have commercial agricultural value. Furthermore, to minimize the potential influence of a few unusual properties (characterized by abnormally low or high prices), only properties priced from \$150,000 to \$450,000 were included. This restriction deleted 59 observations. Within this reduced sample, 21 properties had oil and gas facilities located on them. Because the owners at the time of facility establishment are eligible for financial compensation by the companies owning these facilities, and it was not always possible to determine the timing of facility development relative to the property sale, these properties were excluded from the analysis. After these various exclusions a final sample of 532 sales remained.[3]

The model underlying hedonic price analysis is that the price of a residential property is determined by the buyer's appraisal of those characteristics (Taylor, 2003). This appraisal can involve both objective and subjective evaluations. The number of characteristics can be quite extensive, typically including factors such as structural characteristics (e.g., area, number of bedrooms and the presence of a basement or garage), location attributes (e.g., distance to the central business district, proximity to schools and shopping, etc.) and environmental influences (e.g., views, levels of industrial emissions and noise). The basic attributes of the sample properties were gathered from the Multiple Listing Service (MLS)

[2] For our purposes, the distinction between municipal districts and counties is not relevant.

[3] These restrictions deleted about half of the approximately 30 observations considered influential in the various models. The remaining influential observations were not omitted. Failure to do so does not affect our results. In fact, the pattern of the results is robust across the alternative samples (532, 553 and 612 observations).

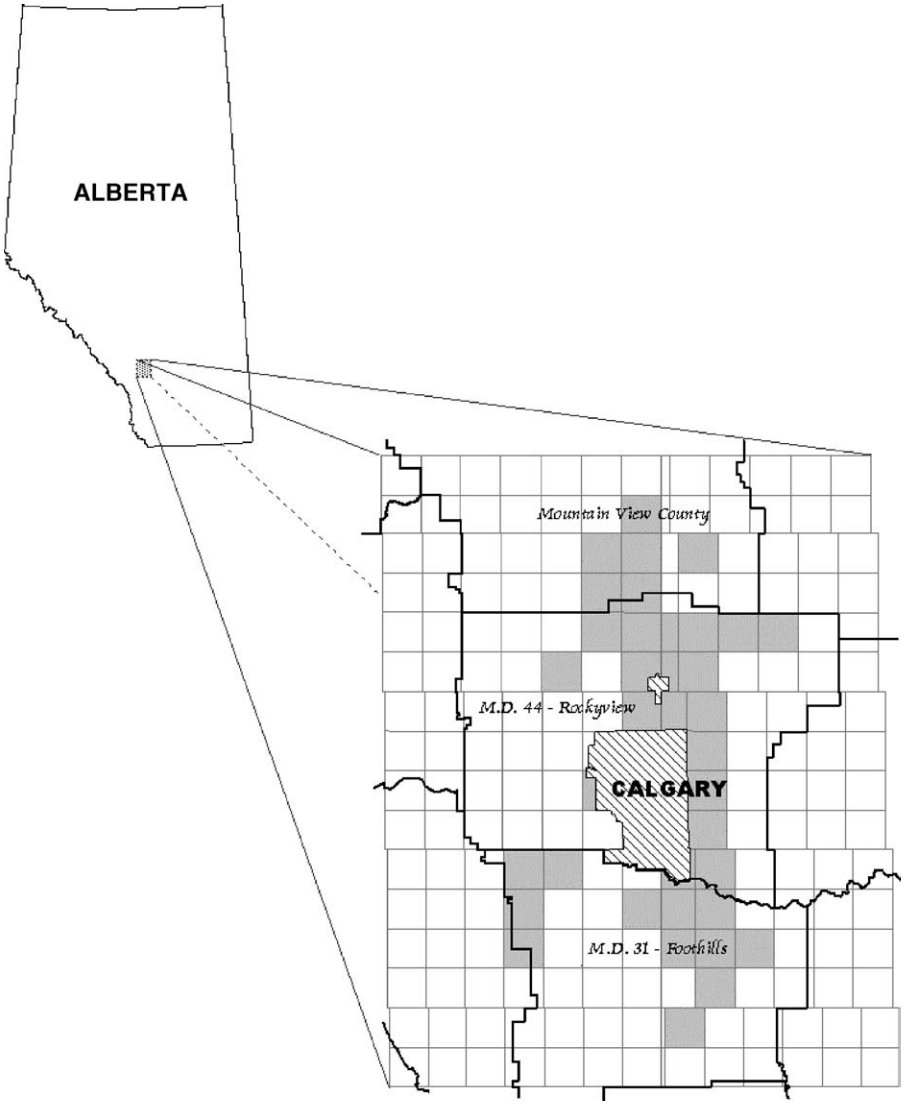


Fig. 1. A map of the study area in Alberta, Canada. Grey areas represent townships in which data on property values and oil and gas infrastructure was collected.

records of the Calgary Real Estate Board. A list and summary statistics of the conventional property attributes are included in Table 1.

Four variables were added that warrant comment. Because many rural residential residents commute to work in Calgary, the distance to downtown Calgary was included. Also, during the 5(+)-year period over which sales data were gathered, house prices in the Calgary market increased considerably. Hence, the real average residential price of property in the City of Calgary (in constant 2000 $CDN) was included to control for the

Table 1
Property attributes from MLS sources[a]

Variable	Description	Mean	S.D.
RPRICE	Sale price of the property (2001 $CDN)	290593.8	69815.48
ACRES	Size of the land associated with the residential structure (acres)	7.15	6.44
AGE	Age of the residential structure at time of sale (years)	10.48	7.94
AREA	Area of the residential structure (m^2)	176.31	63.06
BATH	Number of bathrooms	2.25	0.75
BEDRM	Number of bedrooms	2.91	0.84
CALGARY	Distance from the City of Calgary (km)	31.07	12.23
DECK	Deck or balcony present (DV) [b]	0.67	0.47
NGARAGE	Number of garage spaces for vehicles	2.18	1.09
MUNWATR	Water supplied by municipality (DV)	0.02	0.13
NOBASEMENT	Basement of residential structure is not present (DV)	0.02	0.15
RAVP	Monthly average residential property prices in Calgary (2000 $CDN)	136519.7	9478.30
VMTN	View of the Rocky Mountains	0.40	0.49
ROCKY	Located in Municipal District of Rocky View	0.37	0.48
MOUNTAIN	Located in County of Mountain View	0.05	0.21

[a] Multiple Listing Service.
[b] DV signifies that the variable is a dummy variable (0, 1).

strong housing market in the region. Property values depend partly upon local government taxes and services. Public services are difficult to measure and property tax information was not included in the data. Property taxes are the dominant source of municipal and county government revenue. Hence, dummy variables for the local jurisdiction a property was located in were introduced to capture differences in municipal taxes and services that are reflected in the prices.[4,5] These variables are also described in Table 1.

Numerous other features of the properties were collected and many were initially assessed but ultimately excluded from the final specification. A deficiency of the data was the lack of information on structures beyond the house—that is, out buildings such as stables, barns, corrals and large shops or garages for recreational and utility vehicles.[6] Because horse-back riding is very popular in the area and many properties include significant riding related facilities, this omission is believed to detract from the explanatory power of our regressions.

The principle connections between the presence of oil and gas facilities and residential prices were hypothesized to be visual impacts, noise, traffic, odour and perceived health hazards. Accordingly, additional property attributes were gathered or constructed to

[4] It was not necessary to consider school districts and school financing. While administered by local (district) school boards, schools in Alberta have been fully funded by the province in Alberta since 1995 and a provincial property tax that contributes (about one-third in 2001) to school financing is uniformly levied at a provincial rate. In addition, the school districts match the municipal authorities in the study area.

[5] As reflected in a recent study (Alberta EUB, 2003), the oil and gas industry impacts localities in many ways—for example, direct and indirect jobs, municipal revenues and services. There is no attempt to identify the more obtuse local impacts in this analysis.

[6] The latter may be captured in part by the number of garage spaces variable (Table 1).

Table 2
Oil and gas facility variables

Variable	Description	Mean	S.D.	No. of affected properties in sample
EPZINDEX	Emergency planning zone (EPZ) index (sum of radii of all EPZs a property is located within)	6.83	12.29	246
BATINDEX	Flaring battery index (sum of H_2S released from all batteries within 4 km of property)	49.91	246.83	91
NEAREST	Distance to the nearest operating sour gas plant (km)	16.73	7.01	532
NEPZWELL	Number of well EPZs the property was located within	0.61	2.06	98
NEPZPIPE	Number of pipeline EPZs the property was located within	1.25	2.03	187
FLARING	Number of flaring batteries within 4 km of property	0.31	0.85	91
SWEETWELL	Number of sweet oil and gas wells within 4 km of property	1.94	3.43	250
SOURWELL	Number of sour oil and gas wells within 4 km of property	3.25	3.43	373
ALLWELL	Total number of oil and gas wells (both sweet and sour) within 4 km of property	5.19	4.98	434
ALLPIPE	Total number of pipelines with recorded $H_2S > 0\%$ within 4 km of property	11.31	9.22	495

Source: Alberta Energy and Utilities Board.

characterize the nature, location and extent of any nearby oil and gas facilities. First, each property in the database was located on a Geographical Information System (GIS), and a 4-km buffer was established around each property. The range of 4 km was predetermined by energy experts based on evidence regarding the probable maximum range for impacts that extend from the typical facilities such as wells, pipelines or batteries.

Industry variables were then constructed based upon information held by the Energy Utilities Board. The information used to generate the facility variables came from the Board's GIS databases (accurate to May/June 2001) and information on the EPZs from the emergency response plans submitted by oil and gas companies to the Board. All distance and count measurements were undertaken using the GIS. These variables are described in Table 2.

One group of facility variables was developed to explore the price impacts of the *intensity* of oil and gas developments nearby each property. For each property, the number of natural gas producing facilities within the 4-km buffer of each property was determined. Those included (separately or in combination with oil) sweet gas wells (SWEETWELL), sour gas wells (SOURWELL) and flaring oil batteries (FLARING).

It was expected that property values could be affected by the *proximity* of the various oil and gas facilities. To examine this, the numbers of sour, sweet and oil wells were counted within each of four, 1-km concentric rings around each property. Proximity to sour gas plants was also examined. Plants are few in number and are relatively large processing (versus extraction) facilities. The importance of proximity to the nearest operating sour gas plant (NEAREST) was not limited to the 4 km distance.

In order to focus on the health risk, a second group of variables was selected. Those variables utilized information on the emergency planning zones of the sour gas facilities associated with each property. One measure is the simple counts of the number of EPZs associated with wells (NEPZWELL) or with pipelines (NEPZPIPE) in which a residence is situated.[7] An alternative measure yields a third variable, EPZINDEX, an index of EPZs reflecting the potential volume of escaped H_2S. EPZINDEX was calculated as the sum of the radii (in kilometres) of each of the EPZs overlapping a property. The radius of each EPZ is a function of the potential rate of release of H_2S from the well or pipeline. Thus, a higher EPZINDEX represents a higher potential H_2S exposure intensity or health risk in the event of an emergency.[8] Similarly, the annual volumes of H_2S gas flared at flaring oil batteries within 4 km of a property were summed to construct a flaring battery index (BATINDEX).

Note that pipelines are included in the health risk measures but not the intensity/proximity measures. This distinction was made primarily because data were available only for pipelines carrying natural gas with an H_2S content exceeding 0%. These pipelines are considered sour in this study because they pose some health hazard. Other pipelines, such as those carrying sweet gas and oil, are present but were not included in the data. Pipelines in this area are underground and so are relatively unobtrusive facilities posing minimal amenity problems.

4. The hedonic model and econometric analysis

The hedonic method is one technique in a class of valuation approaches commonly labelled "indirect" valuation. These techniques rely on observable market transactions to obtain values for various characteristics of heterogeneous products. Housing markets are well suited to hedonic methods as the choices of housing location and neighbourhood amenities are observable to researchers. Thus, the choices of properties and their associated prices imply implicit choices of environmental amenities and other characteristics linked to the transacted properties.

In this paper, a first-stage hedonic analysis is reported in which the hedonic price function was estimated using prices and characteristics of a sample of transacted properties. This procedure estimates the implicit prices of the characteristics and reveals information on the underlying preferences for these characteristics. Rosen (1974) suggested the possibility of a second-stage estimation using the implicit prices derived from the hedonic price function and other information to estimate actual household

[7] No EPZ variables were incorporated for sour gas plants directly because the EPZs for gas plants are defined by the zone of the largest volume pipelines serving them. Therefore, the risk of failure for these facilities is described in terms of the pipeline EPZs.

[8] This interpretation of the EPZ index assumes that prospective home-buyers are well informed about the number and size of EPZs in which a property is located. Operators are required to conduct regular tests of their emergency response plan procedures, which include routine contact with residents within a zone and, when a property is sold, it is the obligation of the seller to inform the buyer of the EPZ(s) affecting a property. Thus, property owners should be aware of EPZs and are required to inform potential buyers.

demand for attributes. That step cannot be pursued here because information such as income and household demographics that should be included is lacking.[9]

Three basic issues are involved in constructing a hedonic price model. Two of these, functional form and model specification, are common to all hedonic price analyses. While a range of hedonic price function specifications are possible, this study used the double log specification which was chosen based on preliminary Box–Cox regression procedures and confirmed by LM tests developed by Baltagi and Li (2001) for the specifications reported here. Cropper et al., 1988 have shown that the log–log function is best in terms of measuring marginal prices in the presence of model misspecification relative to linear, linear–log and other quadratic functions. The log–log formulation provided the best fit and allowed construction of price elasticities that aid in the interpretation of the implicit price coefficients. A small constant was added to all non-dummy variables with zero values before logarithmic transformation. Adding a small constant before logarithmic transformation is not uncommon (Antweiler and Frank, 2002; Jacoby, 1992; MaCurdy and Pencavel, 1986).

To determine the specification of the hedonic model, property prices were regressed against both the property (non-industrial) variables and certain combinations of the (industry) facility variables. All facility variables could not be included in the model due to concerns regarding multicollinearity. Final choice of facility variables in the specification involved consideration as to whether the variable likely represented an amenity concern or a health concern. After considerable testing, two health risk specifications and two amenity specifications were chosen. The first health risk model (H1) involved the two index variables, EPZINDEX and BATINDEX and a proximity variable, NEAREST. The second health risk model (H2) included three frequency variables, FLARING, NEPZWELL and NEPZPIPE. Both amenity specifications involved frequency variables; the first (A1) focused on the two types of wells (SOURWELL and SWEETWELL) and the second (A2) used the total number of wells and pipelines (ALLWELL and ALLPIPE).

The third issue involves the treatment of spatial dependencies and whether spatial considerations should be formally considered in the error structure of the model. Spatial dependencies affect hedonic studies from either structural relationships among the observations (lagged dependency) or from the omission of spatially correlated explanatory variables that impact the spatial dependency among the error terms. Researchers have demonstrated the importance of accounting for spatial dependencies in hedonic applications (e.g., spatial lagged dependencies (Can and Megbolugbe, 1997; Gawande and Jenkins-Smith, 2001) and spatially autocorrelated errors (Bell and Bockstael, 2000; Leggett and Bockstael, 2000)).

Anselin (1988) describes spatial regression models that attempt to incorporate these effects. Spatial dependence can be incorporated using a spatial lag model that is defined in the following equation using the double log functional form:

$$\ln Y = \alpha + \rho W \ln Y + \beta \ln \mathrm{X_c} + \delta \mathrm{X_d} + u \quad (1)$$

[9] The second-stage process is fraught with endogeneity and identification problems that, despite considerable effort and ingenuity (see Taylor, 2003), have led at least one group of analysts to conclude that the method has not yet been used successfully to estimate willingness to pay functions (Deacon et al., 1998).

In this equation, Y represents property prices, X_c are continuously measured property attributes and industry variables, δ is the vector of intercept shifts that correspond to attributes measured using dummy variables X_d, and $u \sim N(0, \Omega)$. The effect of the spatial lag is assessed through the parameter ρ and a spatial weighting matrix W, which defines the spatial relationships among the property prices. Alternatively, the spatial error model suggested by Anselin (1988) with the double log functional form is defined by:

$$\ln Y = \alpha + \beta \ln X_c + \delta X_d + \varepsilon \quad (2)$$

$$\varepsilon = \lambda W \varepsilon + u \quad (3)$$

This model includes a normal disturbance $u \sim N(0, \Omega)$, a spatial weighting matrix (W) and a coefficient (λ) for the spatial autoregressive structure for the disturbance (ε). A non-zero λ-value represents the presence of spatial errors and if present, OLS estimates will be unbiased yet inefficient.

Because the data analyzed in this study were spatial in nature, these spatial issues were examined. A key element in this approach is the determination of the "spatial weighting matrix" which involves selecting the properties within a certain range or distance of the given property and determining the relative weight of each on the property of interest. Guided by various specifications in the spatial hedonic literature (e.g., Bell and Bockstael, 2000) a number of specifications of the weighting matrix were examined. A matrix of the inverse distances between properties ($1/d_{ij}$) within 4 km was chosen as the spatial weighting matrix in which the diagonal elements contain zero values:

$$W = \begin{bmatrix} 0 & & & & \\ \frac{1}{d_{1,2}} & 0 & & & \\ \frac{1}{d_{1,3}} & \frac{1}{d_{2,3}} & \ddots & & \\ \vdots & \ddots & \ddots & 0 & \\ \frac{1}{d_{1,N}} & \cdots & \cdots & \frac{1}{d_{N-1,N}} & 0 \end{bmatrix}$$

Specifications using distances of 1, 2 and 10 km were examined; the $(1/d)^2$ form was tried, and weights matrices producing a lattice structure by including only 2, 3 or 5 of the closest neighbours were examined. While these various specifications did not produce results appreciably different than those reported here, intuitively it was felt that properties which are further apart should be given smaller weight due to the minimal impacts they might have on each other. Thus, the distance specifications were preferred over the lattice structure. The 4 km distance was chosen because the 1 km limit (especially) seems rather tight for this data and also because it matches the 4 km cut-off used to study the facility impacts.

A researcher must select a spatial autoregressive model by testing for the presence of a spatial lag ($\rho \neq 0$) or spatial error ($\lambda \neq 0$) through a variety of statistical tests. In addition to the standard Lagrange Multiplier (LM) tests, robust LM tests and Kelejian and Robinson (1999) tests are often performed to provide additional evidence for the spatial error structure. Moran's I-test can be used as a general test of model misspecification when considering the presence of spatial effects. The Kelejian and Robinson test is designed for the same purpose with the additional features of being robust to non-normality of the error terms and non-linear structure in the price equation. While it is possible that independent tests suggest that both a lag and an error model are appropriate, Anselin and Florax (1995) suggest that comparison of the statistical significance of LM tests and robust LM tests will identify the superior specification for capturing spatial dependence.

The results presented below involve models chosen on the basis of the overall fit and statistical significance of the individual parameters. Due to the number of variables assessed in this study, and that the parameters of the property characteristics are of secondary interest and are not sensitive to the inclusion of the facility variables, we present the parameters for the property characteristics and facility variables separately for ease of presentation.

5. Results and discussion

5.1. (Non-industrial) property characteristics

Table 3 presents OLS parameter estimates for the non-industry property characteristics associated with the residence gathered from the standard real estate Multiple Listing Service forms. The characteristics having significant coefficients are AGE, AREA, the number of bedrooms (BEDRM), the number of bathrooms (BATH), the presence of a deck (DECK), the number of garage spaces (NGARAGE), the size of the property (ACRES), a view of the mountains (VMTN), distance from the City of Calgary (CALGARY), the inflation adjusted monthly average price of residential property in Calgary (RAVP) and Municipal District of Rocky View (ROCKY) and the County of Mountain View (MOUNTAIN). Since the local government dummy variables are not significantly different from each other in any of the three models in Table 3 (F-tests; $P > 0.30$), there is a significant difference in prices between similar properties in these two jurisdictions and those in the Municipal District of Foothills.

All of the signs of the parameters are as expected. For example, the larger the area of the residence, the greater its price. Also, the marginal impacts of these variables on price appear to be reasonable (see Appendix A). Note that the impact of an added bedroom is negative but that reflects that the area (and number of bathrooms) in the house remain the same. That is, another bedroom is ‘‘squeezed’’ into the average sized house. Robust t-ratios were also calculated due to the presence of heteroskedasticity indicated by the Breusch–Pagan test results are reported in Table 3. The statistical significance of no variable changed as a result of using the robust t-ratios.

The property characteristics model was then subjected to spatial adjustment and further statistical testing. The results supported the use of the spatial error model over the spatial lag. Inclusion of the jurisdiction dummy variables (ROCKY and MOUNTAIN) removed evidence of spatial lag. However, the spatial error parameter was found to be positive and significant at the 1% level (Table 3; last column). Upon adjustment of the error term, the parameters of the property variables did not change appreciably except for MUNWTR which was found to be statistically significant in the spatial results but not for the non-spatial results.

Table 3
Regression results for the hedonic model of property characteristics on prices

Non-industry Characteristics	OLS (*t*-ratio)	OLS (Robust *t*-ratio)	Spatial error (*t*-ratio)
INTERCEPT	−1.1650 (1.1345)	−1.1650 (1.1399)	−0.1246 (0.1291)
ln(AGE)	**−0.0178**[a] (2.2401)	**−0.0178** (2.3972)	**−0.0185** (2.4734)
ln(AREA)	**0.3884** (17.0194)	**0.3884** (14.0514)	**0.3518** (16.2612)
ln(BEDRM)	**−0.1010** (4.9116)	**−0.1010** (4.6536)	**−0.0765** (4.1461)
ln(BATHRM)	**0.0752** (4.0596)	**0.0752** (3.5506)	**0.0744** (4.4419)
NOBASEMENT	−0.0314 (0.7735)	−0.0314 (0.7437)	−0.0529 (1.4364)
DECK	**0.0324** (2.5111)	**0.0324** (2.4305)	**0.0296** (2.4944)
ln(NGARAGE)	**0.0789** (5.3260)	**0.0789** (4.7299)	**0.0804** (5.7397)
ln(ACRES)	**0.0922** (10.4423)	**0.0922** (10.1550)	**0.0917** (10.1486)
VMTN	**0.0279** (2.2501)	**0.0279** (2.1973)	**0.0276** (2.2475)
MUNWTR	0.0812 (1.7225)	0.0812 (1.9115)	**0.0946** (2.1911)
ln(CALGARY)	**−0.1744** (8.0164)	**−0.1744** (7.4646)	**−0.1734** (5.8598)
ln(RAVP)	**1.0296** (11.8386)	**1.0296** (11.9227)	**0.9553** (11.7621)
ROCKY	**−0.1015** (7.4950)	**−0.1015** (7.5967)	**−0.0983** (5.0629)
MOUNTAIN	**−0.1183** (3.3462)	**−0.1183** (3.1067)	**−0.1119** (2.4953)
λ			**0.4239** (7.6757)
Adjusted R^2[b]	0.6739		0.6811
Multicollinearity condition number	2.7361		
Jarque–Bera test on normality	0.1738		
P-value	0.9167		
Breusch–Pagan test for heteroskedasticity	26.0762		
P-value	0.0253		

[a] Parameter estimates in bold indicate significance at 5% level for a two-tailed test.
[b] The R^2 reported for the spatial error model is the squared correlation between the predicted values and the actual values of the dependent variable.

5.2. (Industrial) facility characteristics

Having chosen a "base" set of property characteristics, combinations of facility variables were added to the hedonic model to arrive at the results presented in Table 4. The property variables in Table 3 were included in these models but since the associated coefficients are not substantially different when facility characteristics are included, the coefficients for these variables are not reported.

The combinations of facility characteristics in each model in Table 4 were chosen based upon consideration of the correlations among the facility variables and whether the combinations represented perceived hazard or amenity effects. The significant Moran's *I*-statistics lend support to consideration of spatial dependencies. Thus, all of these models were spatially adjusted. While both spatial tests were employed, regression diagnostics continued to suggest that when industry characteristics were added, spatial error effects were present in the data as shown by the LM tests and their robust counterparts reported in the bottom of Table 4. In each case, the tests suggest that the spatial error specification be chosen over the spatial lag because the associated LM statistics for the spatial error models were larger and more statistically significant than those from the spatial lag models. The significant Kelejian–Robinson statistics also lend support to the use of spatial error specification. The superiority of the spatial error model holds across all of the hazard and amenity specifications reported below.

Table 4
Spatial error hedonic models for the effects of oil and gas facilities on property prices[a]

Industry variables	Hazard H1 (*t*-ratio)	Hazard H2 (*t*-ratio)	Amenity A1 (*t*-ratio)	Amenity A2 (*t*-ratio)
ln(EPZINDEX)	−**0.0182**[b] (2.5483)			
ln(BATINDEX)	−**0.0113** (2.6011)			
ln(NEAREST)	−0.0036 (0.1560)			
ln(FLARING)		−**0.0541** (2.6715)		
ln(NEPZWELL)		−0.0253 (1.5327)		
ln(NEPZPIPE)		−**0.0319** (2.9037)		
ln(SOURWELL)			−**0.0311** (3.2963)	
ln(SWEETWELL)			−0.0181 (1.5930)	
ln(ALLWELL)				−**0.0410** (3.6722)
ln(ALLPIPE)				0.0104 (1.0933)
λ	**0.3889** (6.7782)	**0.3920** (6.8531)	**0.3577** (6.0409)	**0.3655** (6.2195)
R^2 (Buse)[c]	0.9672	0.9678	0.9613	0.9629
Moran's *I*-test	7.3166	7.7614	6.8661	7.0791
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
LM test (error)	43.5302	49.3745	38.7233	41.3565
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Robust LM test (error)	42.2604	47.9214	37.5261	39.9373
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
Kelejian–Robinson (error)	121.2155	162.6337	190.1173	208.3861
P-value	[0.0000]	[0.0000]	[0.0000]	[0.0000]
LM test (lag)	4.6055	5.0801	4.6081	5.9726
P-value	[0.0318]	[0.0242]	[0.0318]	[0.0145]
Robust LM test (lag)	3.3357	3.6274	3.4109	4.5534
P-value	[0.0678]	[0.0568]	[0.0648]	[0.0329]

[a] Not reported in this table are the coefficients for the property characteristics found in Table 3 that were also included in each estimated model.

[b] Parameter estimates in bold indicate significance at 5% level for a two-tailed test.

[c] The R^2 reported for the spatial error model is the adjusted R^2 measure adjusted for non-spherical errors (Buse, 1973).

Additional specification tests were conducted on the oil and gas facility models and the results are reported in Table 5. First, LM tests devised by Baltagi and Li (2001) were conducted to simultaneously test for functional form and spatial error. The log–log specification in the presence of spatial errors was supported by the insignificance of the test results (Table 5). Second, the problem of heteroskedasticity was examined using Breusch–Pagan tests. The resulting statistics suggest that this problem may be present, but none of the statistics were significant at the 5% level. The statistic for the H1 model exhibited the level of significance closest to the 5% level.

Hazard model H1 in Table 4 includes the EPZINDEX for wells and pipelines, the annual volume of gas flared from neighbouring batteries (BATINDEX), and the distance to the nearest operating sour gas plant (NEAREST). Both the EPZINDEX and the BATINDEX

Table 5
Specification tests for spatial error hedonic models for the effects of oil and gas facilities on property prices

	Models			
	H1	H2	A1	A2
Test for log–log model and spatial error				
LM test[a]	0.2544	0.6851	0.5825	0.4497
P-value	[0.6139]	[0.4078]	[0.4453]	[0.5024]
Test for heteroskedasticity				
Spatial Breusch–Pagan test	26.4089	24.9566	22.6888	23.5729
P-value	[0.0673]	[0.0956]	[0.1223]	[0.0992]

[a] LM tests from Baltagi and Li (2001) were used to test the null of double log model conditional on the presence of spatial error structure.

parameters were negative and statistically significant, while NEAREST has a negative influence on property value as expected, but was statistically insignificant. The insignificance of the NEAREST coefficient may be partly due to the relatively high, −0.51, correlation with EPZINDEX and the fact that observations nearby plants, and so most likely affected, will also be in EPZ areas. Hazard model H2 included the number of well and pipe EPZs affecting the property (NEPZWELL and NEPZPIPE) and the number of flaring batteries within 4 km (FLARING). All three parameters were negative and those for NEPZPIPE and FLARING are significant, suggesting that these facilities lowered property prices consistent with expectations. The number of well EPZs was statistically insignificant, however, which may be explained by the small number of properties (98) in the sample affected by well EPZs (Table 2).

The amenity models concentrated on the number and proximity of facilities rather than their sour gas content. The numbers of sour and sweet wells within 4 km of each property (SOURWELL and SWEETWELL) were incorporated into amenity model A1. Pipelines, which are less conspicuous, were ignored. The coefficients of both the well variables are negative but that for the number of sour wells was significant at the 5% level while that for the number of sweet wells significant only at the 15% level. The marginal effect of the sour wells on prices is almost twice the size of that from the sweet wells. Because one cannot disentangle the hazard effect of the sour wells from their amenity impact, one should expect a larger impact for the sour wells. Amenity model A2 divided facilities into the total number of wells (both sour and sweet together, ALLWELL) and the total number of sour pipelines (ALLPIPE). (Recall that we have no data on pipelines not carrying sour gas.) The results suggest that it is the total numbers of wells but not the number of sour pipelines that have significant negative impacts on property prices.

A variety of unreported models were also estimated. The general pattern of the results in these is similar to those described above, but some outcomes merit noting. In numerous cases (various specifications and with some variations in the data), the coefficients for sweet and sour wells were both significantly negative. Also, the coefficient for the sweet wells was typically less than or, at most, equal to that for sour wells suggesting an added penalty for sour wells. An effort was made to assess proximity to wells by distinguishing

Table 6
Marginal and mean effects of the presence of oil and gas facility variables on the average property price

Facility variable	Mean level of the variable in the sample (S.D.)	Price effect from 0 to the first unit of the variable	Price effect from 0 to the mean level of the variable	Marginal effect at the mean level of the variable
EPZINDEX**	6.83 (12.29)	−3647.61	−10698.29 (−15470.56)[a]	−676.10 (−263.13)
BATINDEX**	49.91 (246.83)	−2271.38	−12645.85 (−18147.92)	−64.62 (−11.05)
NEAREST	16.73 (7.01)	−717.42	−2904.84 (−3263.85)	−61.94 (−43.86)
FLARING**	0.31 (0.85)	−10702.70	−4174.46 (−11867.57)	−12042.53 (−7282.91)
NEPZWELL	0.61 (2.06)	−5044.35	−3487.41 (−9389.53)	−4552.22 (−2000.53)
NEPZPIPE**	1.25 (2.03)	−6350.31	−7399.44 (−13152.57)	−4124.28 (−2166.31)
SOURWELL**	1.94 (3.43)	−6206.40	−12805.28 (−17881.68)	−2129.64 (−1177.98)
SWEETWELL	3.25 (3.43)	−3621.51	−5614.59 (−9570.23)	−1788.38 (−825.92)
ALLWELL**	5.19 (4.98)	−8148.20	−20942.20 (−27394.35)	−1926.27 (−1067.51)
ALLPIPE	11.31 (9.22)	2110.78	7718.81 (9465.22)	246.40 (140.88)

(**) Refers to the whether the facility variable is significant at the 5% level.
[a] All effects are reported in 2001 Canadian dollars. Numbers in parentheses for the effects refer to the effect with one standard deviation added.

those in successive one kilometre concentric rings on the property (i.e., less than 1 km, 1–2 km, etc., up to 4 km) and employing econometric procedures similar to those used by Palmquist et al. (1997) in their analysis of the effect of hog operations on property values.[10] Other than revealing that wells within one kilometre had the greatest impact on price, the other coefficients did not demonstrate a consistently diminishing effect. Information on whether facilities predated our study period or were built after 1993 provided some interesting insights. The age of wells did not matter. However, ‘‘new’’ post-1993 pipelines typically had a significant negative effect on price; perhaps because the disruption of their construction was still more clearly visible.

5.3. The marginal impacts of industry facilities

Table 6 presents the marginal sale price effects of the oil and gas facility characteristics on the price of the average property in the database in a number of different ways. First, the marginal effect from 0 to 1 represents the impact of the introduction of the first unit of a typical facility on the price of the average property. Second, the mean level effect refers to the effects of the presence of facilities at the average level for that facility type in the sample. Finally, the marginal effect at the variable mean refers to the impact of an additional unit of a facility given that the average property already is impacted by existing facilities of the type under consideration. To demonstrate the pattern over a broader range, the price and marginal effects are also presented at the mean plus one standard deviation.

The price effects in Table 6 indicate that proximity to and H_2S volumes of EPZs and gas flaring batteries as measured by the two index variables EPZINDEX and BATINDEX have significant negative effects on property values. EPZINDEX, which refers to a weighted sum of all EPZ sizes overlaying properties, has a first unit effect of −$3647.61 and a total

[10] Because our data did not include facilities beyond 4 km from a property, it was not possible to explore for potential impacts of more distant facilities.

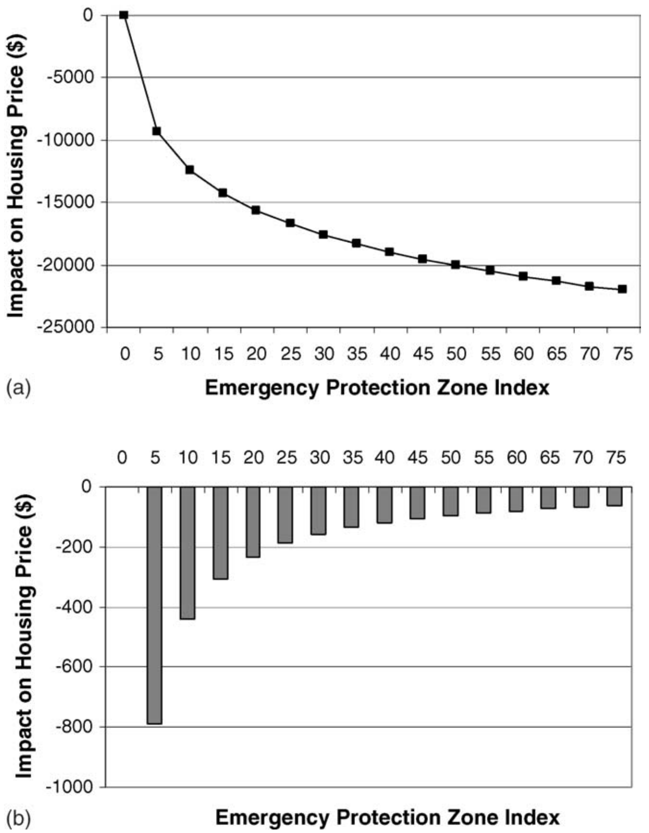


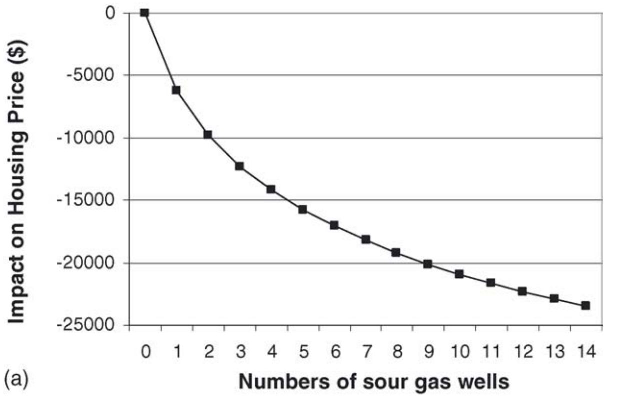
Fig. 2. The effects of increasing the exposure of rural residential properties to sour gas hazards as measured by the emergency planning zones index (EPZINDEX); (a) presents the cumulative effects of additions to the index and (b) presents the marginal effects of increases in the index.

effect at its mean level (6.83) of −\$10,698.29 or approximately 3.8% of the value of the average property. The marginal effect on price declines from −\$3647.61 to −\$676.10 at the mean and to −\$263.13 at the mean plus one standard deviation level (19.12). Fig. 2 illustrates further the diminishing effect of additional increments to the EPZINDEX. Fig. 2a shows the total effect on price of the average property as EPZINDEX levels increase and Fig. 2b shows the marginal values at the different levels. A similar conclusion can be made for the flaring battery index (BATINDEX, which represents the weighted sum of the annual volume of flared solution gas in units of m^3) and for which a similar pattern is found. The impact of the first unit is −\$2271.38, the mean level effect is −\$12,645.85 (which is a decline of approximately 4.3% of the average price) and the marginal value at the mean is −\$64.62.

Hazard model H2 gives results similar to those of the two indices reported above. The presence of the first flaring battery within 4 km (FLARING) causes a decline of −\$10,702.70 in price. This is the highest first-unit marginal value among the 10 facility variables examined in Table 6. At the mean plus one standard deviation value for

FLARING (1.16 batteries), the total level impact is −$11,867 and the marginal effect is −$7283. The number of pipeline EPZs (NEPZPIPE) has a first-unit effect on value of −$6,350.31 and the price effect at the mean level (1.25 EPZs) is −$7399. At the mean level, the marginal impact declines to −$4124. Both hazard models indicate that the presence of oil and gas facilities cause significant negative effects on property values in proximity to the facilities examined.

Turning to the amenity variables, the marginal effects of the presence of wells on price are similarly negative. Sour wells (SOURWELL) have a much higher impact than sweet wells (and recall that the sweet well parameter was significant at the 15% level only). However, the combined effects of both sour and sweet wells (ALLWELL) are also negative and larger in magnitude (Table 4). Introduction of a sour gas well reduces price by $6206 while the reduction at the mean of 1.94 wells amounts to $12,805 and the reduction when the number is increased to the mean plus one standard deviation (5.37 wells) is $17,882. The marginal effects of adding sour wells drops rapidly, from −$6206 for the first well, to −$2129.64 at the mean number of wells, and to −$1178 at the mean plus one S.D. of 5.37 wells. These effects are illustrated further in Fig. 3a and b. The combined effects of both



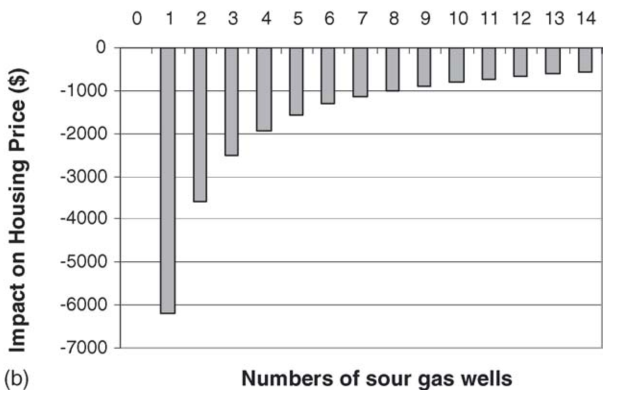


Fig. 3. The effects of increasing the number of sour gas wells within 4 km on the average prices of rural residential properties in Alberta; (a) presents the cumulative effects of additional wells and (b) presents the marginal effects.

sour and sweet wells are also negative. The total number of wells (ALLWELL) is more influential with a first-unit effect of −$8148.20 and a mean effect (at 5.19 wells) of −$20,942.20, representing approximately 7% of average property value.

One can employ the amenity model parameters to make some estimates of the hazard effect of wells with H_2S present independent of the amenity effects. Sour wells have both an amenity impact and a hazard impact while sweet wells likely have only an amenity effect on property values. While the magnitude of the hazard is not measured by the SOURWELL variable, these wells are known to have H_2S present and so present some health risk. Similarly, ALLWELL has a sour well component and thus some associated risk. Accepting the SWEETWELL parameter estimate as a valid approximation of the magnitude of the impact of the presence of H_2S risk-free wells on property prices even if significant at only the 15 percent level, allows attribution of the difference between that and the sour well effect caused by the presence of H_2S. For example, the first sweet well reduces the average property's value by $3621 while the first sour well reduces the value by $6206. These amounts imply an extra cost to the sour gas well of $2585. The ALLWELL parameter implies a somewhat higher cost per well; $8148 for the first well, which would be a combination (0.373:0.626) sweet to sour. Extrapolating from this estimate, the extra cost of the initial well being sour as opposed to sweet is $4006. At the mean number of 5.19 wells, if all were sour, the market value of the average property would be reduced by $14,507 while, if all those wells were sweet wells, the reduction would be $8533. The extra effect of the sour gas is $5974. Similarly, if the ALLWELL parameter is used, the estimate of the additional impact on price due to the presence of sour gas is $9359. Hence, it appears that property buyers discount properties neighbouring oil and gas wells and even when relying upon variables that do not account specifically for health hazards, it appears that they discount more heavily those posing a health hazard due to sour gas.

6. Conclusions

The results of this analysis strongly suggest that the presence of oil and gas facilities can have significant negative impacts on the values of neighbouring rural residential properties. These results contrast with those of earlier consulting reports addressing this question in the Alberta context. However, given the relatively extensive (though admittedly not ideal) data and the use of current methodologies—specifically, a double log hedonic model with spatial error adjustment—plus the reasonableness of the magnitudes and behaviour of the estimates, we have confidence in the outcomes presented.

Measures of both hazard and (dis)amenity attributes were found to have negative effects on property values. Hazard characteristics included either volume of hazardous gas indexes or number of hazardous zones measures. Measures of both types had significant coefficients. Number of wells measures or the number of wells and pipelines were variables in the amenity models. The presence of wells, especially sour gas wells, was found to depress property values but the number of pipelines carrying sour gas variable did not have a significant coefficient. At the mean level of industry facilities within 4 km, property values are estimated to be reduced between 4 and 8 percent. The impact can easily be twice that depending upon the level and composition of the nearby industry activities—for example, if all the wells in the 4-km zone were sour gas wells rather than the typical mix of sour gas and other wells.

To our knowledge, this is the first academic study of the implications of oil and gas production facilities upon property values. While, naturally, the results must be considered with some caution (and await further investigation to confirm, refine or refute), they are broadly consistent with studies of the impacts of other industries having potentially detrimental influences on the use and enjoyment of property. As such, we believe the impacts implied by this analysis and the estimates derived will be of interest to and potentially valuable to residents, firms, the oil and gas industry and regulators. For example, the estimates indicate that there are negative economic consequences related to proximity to certain (but not all) types of industry facilities and this evidence may help all to better understand the economic reasons underlying concerns and disagreements. In addition, this work may assist all the players in making better site decisions and regulators, in particular, in mediating disputes and in assessing the merits for compensation should a facility be introduced near existing rural residential property.

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Appendix A

Marginal price effects of the property attributes

Name	Mean	S.D.	Minimum	Maximum	Marginal values at mean	95%C.I. upperbound[a]	95%C.I. lowerbound[a]
AGE**	10.48	7.94	1.00	99.00	−514.27	−106.75	−921.80
AREA**	176.31	63.06	73.10	546.20	579.87	649.77	509.98
BED**	2.91	0.84	1.00	8.00	−7633.09	−4024.65	−11241.52
BATHS**	2.25	0.75	1.00	7.00	9591.16	13823.27	5359.05
NOBASEMENT	0.02	0.15	0.00	1.00	−15376.16		
DECK**	0.67	0.47	0.00	1.00	8602.33		
GARAGE**	2.18	1.09	0.00	6.00	7342.97	9850.44	4835.49
ACRES**	7.15	6.44	1.00	40.00	3727.00	4446.80	3007.21
VMTN**	0.40	0.49	0.00	1.00	8017.92		
MUNWTR**	0.02	0.13	0.00	1.00	27481.89		
CALGARY**	31.07	12.23	9.40	72.20	−1621.48	−1079.12	−2163.84
RAVP**	136519.7	9478.3	118126.9	153993.2	2.03	2.37	1.69
ROCKY**	0.37	0.48	0.00	1.00	−28578.85		
MOUNTAIN**	0.05	0.21	0.00	1.00	−32507.57		

(*) Refers to 10% significance and (**) refers to 5% significance.

[a] Refer to the confidence limits of the mean of the property attribute.

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