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# The impact of mining and smelting activities on property values: a study of Mount Isa city, Queensland, Australia

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Much publicity has been given to the problem of high levels of environmental contaminants, most notably high blood lead concentration levels among children in the city of Mount Isa because of mining and smelting activities. The health impacts from mining-related pollutants are now well documented. This includes published research being discussed in an editorial of the Medical Journal of Australia (see Munksgaard *et al*. 2010). On the other hand, negative impacts on property prices, although mentioned, have not been examined to date. This study rectifies this research gap. This study uses a hedonic property price approach to examine the impact of mining- and smelting-related pollution on nearby property prices. The hypothesis is that those properties closer to the lead and copper smelters have lower property (house) prices than those farther away. The results of the study show that the marginal willingness to pay to be farther from the pollution source is AUS $13 947 per kilometre within the 4 km radius selected. The study has several policy implications, which are discussed briefly. We used ordinary least squares, geographically weighted regression, spatial error and spatial autoregressive or spatial lag models for this analysis.

**Key words:** hedonic price model, mining- and smelting-related pollution, Mount Isa, property (house) prices, spatial analysis.

## 1. Introduction

In recent years, publicity has been given to the problem of negative impacts of mining activities on surrounding communities and the environment in Australia. The negative impacts on communities referred to are mainly on health and property prices.[1] While some of the health impacts from mining-related pollutants such as lead are quite well documented and discussed (see, for example, Jones 2009; Anonymous 2010; Munksgaard *et al*. 2010) and some health studies are ongoing, the impacts on house prices, although mentioned in newspapers (see, for example, Cartwright 2010), are not examined in any detail. The present study addresses this issue using the hedonic property (HP) price approach.

The city of Mount Isa is an ideal site to conduct an HP price study to determine the impact of pollution on property (house) prices. First, the health

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[1] The property prices in this study refer only to residential properties.


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impacts from pollutants from mining and smelting are well known and documented, and much publicity has been given to this problem. Second, growth of the city of Mount Isa – which dates back to the 1920s – has evolved in such a way that the population of approximately 19 500 residents is living both in close proximity and farther from the source(s) of pollution. This enables selecting a relevant sample for a study of this nature. Third, the data for this study are available from many sources, including RPData, Australian Bureau of Statistics (ABS) and Google Maps.

Mount Isa is a city that has grown and owes its existence, to a large extent, to mining and smelting activities. At the same time, most residents are affected by the very activities that a large majority of the community rely on for their livelihood, either directly or indirectly. Emissions from mining and smelting activities have been a concern and have been frequently monitored (see, for example, Environmental Protection Agency, 2001). In this study, it is hypothesised that pollution is an issue that residents and buyers are aware of and of its effects on property (house) prices. Hence, it is hypothesised that properties (houses) close to the source(s) of pollution have lower prices than those that are located farther away. In other words, residents are willing to pay (WTP) more to be farther from the pollution source(s) in order to minimise pollution hazards.

The results of this study have important policy implications. As the literature review shows, mining and smelting activities have had an impact on the health of residents, especially children. This study provides evidence that mining and smelting activities also impact on property (house) prices. These are persuasive reasons for relocating residential housing and public utilities (e.g. schools and supermarkets) away from mining-related activities. The key issue of course relates to the cost of relocation. It is argued here that based on the results of this study, the relevant authorities should take into account the health costs as well as the impacts on property prices when considering the costs and benefits of relocation. The benefits may well justify the costs of relocation in the long term.

The study is set out as follows. Section 2 provides a brief introduction to the study. Section 3 covers the literature review, and Section 4 deals with the data and the estimated models. The regression results are discussed in detail in Section 5. Section 6 concludes with a discussion of the main results and a potential solution to minimise the harmful impacts on the community and property (house) prices.

## 2. A brief introduction to the study area and its pollutants

As mentioned earlier, Mount Isa was selected to study the impact of negative externalities arising from pollution because of its mining and smelting activities. The particular negative externality that has been discussed widely is the impact of lead pollution and airborne pollutants such as total suspended particulate matter on residents' health, especially children in Mount Isa. Studies conducted elsewhere, too, have confirmed that such pollution impacts on human health (see, for example, Gulson *et al.* 1998; Pope *et al.* 2002; Heyworth and Mullan 2009; Jones 2009). The impact on residents' health from mining- and smelting-related pollution (e.g. lead) in Mount Isa is, therefore, assumed to have an impact on nearby property (house) prices as well. It is acknowledged that these 'pollution effects' may have been magnified because of the considerable publicity generated in the local and national media about the incidence of lead poisoning, especially among children close to where the lead smelting takes place (see, for example, Gerard 2006; Dayton 2007; Ryan 2008; Ryder 2010). The issue of lead poisoning at Mount Isa has also been discussed in medical journals such as the Medical Journal of Australia (see, for example, Munksgaard *et al.* 2010). As would be expected, information provision about negative externalities is likely to result in it being less appealing for residents to live in close proximity to the source of the externality. This would be reflected in lower property (house) prices.

The district of Mount Isa is located in North Queensland, Australia, approximately 900 km to the west of Townsville and approximately 1900 km north-west of Brisbane. It borders the Northern Territory (NT) to the west where no residential settlements can be found. The distance to the NT border is approximately 152 km. The district itself takes its name from the mining city of Mount Isa. The Mount Isa City covers 43 310 square kilometres and had a population of 19 663 (52.6 per cent men) in the 2006 census (ABS, 2006), which increases to approximately 30 000 when the surrounding district is included (ABS, 2006). The median rent per week in the city of Mount Isa in 2006 was $150, and the average household size was 2.7. Most of the employed residents (5536 persons) commuted to work by car (ABS, 2006).

Mount Isa is the administrative, commercial and industrial city for Queensland's north-western region (see Figure 1). The city's main industrial activity is mining, and it has one of the most productive single mines in the world – Mount Isa Mines – based on combined production of lead, copper, silver and zinc (see, for example, Net Resources International, 2011). Most of the major mining activities date back to the 1920s, and full production occurred in the early 1930s (ABS, 2006).

Over the past decade, the widespread publicity relating to negative environmental externalities in Mount Isa has concentrated on lead pollution. Lead poisoning of residents in Australia is not a new phenomenon, and pollution of this nature has occurred in Port Pirie (South Australia) in the early 1980s and in Broken Hill and Boolaroo (New South Wales) in the early 1990s (Gulson *et al.* 1998). In Mount Isa, high blood lead concentration levels have been confirmed since 1994 and have been the subject of much discussion since then (see, for example, Munksgaard *et al.* 2010). In addition to the above-mentioned areas, in more recent times, lead poisoning fears have arisen in the port of Fremantle as a result of the escape of carbonate during loading of shipments (Heyworth and Mullan 2009; Cartwright 2010). New lead poisoning fears and its impact on property prices have also surfaced because of the

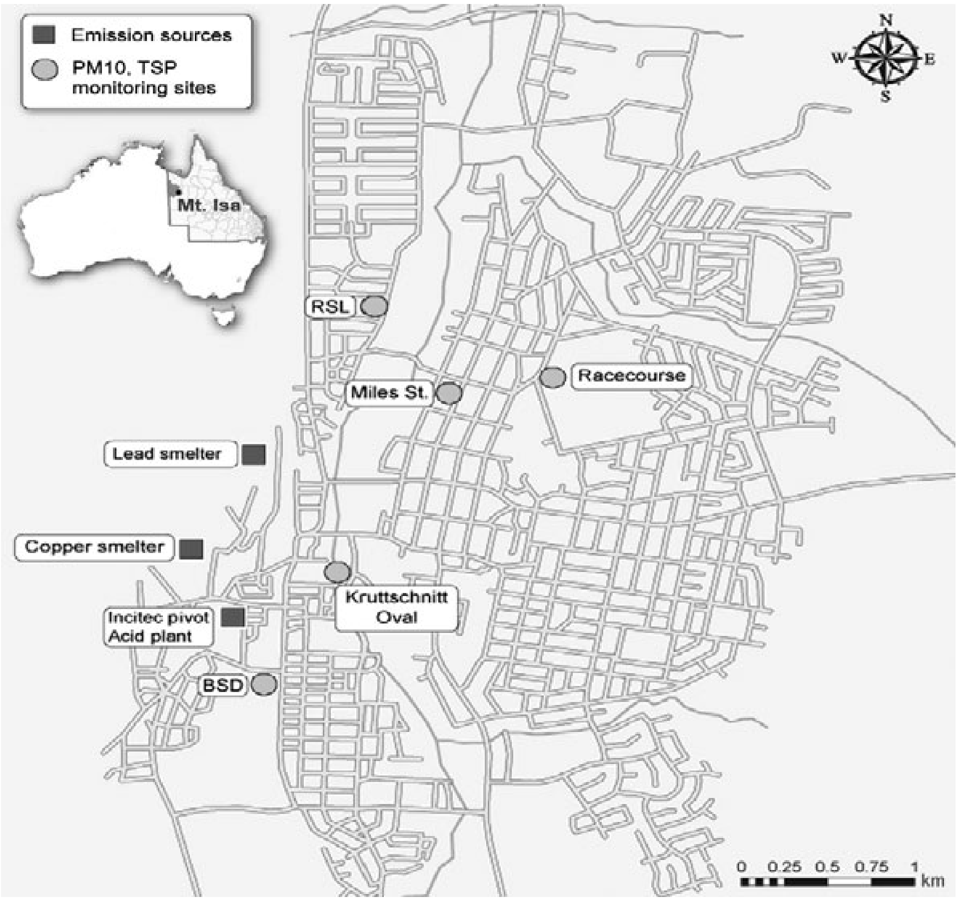


**Figure 1** Lead and copper smelters and monitoring stations. Source: Adapted from Department of Environment and Resource Management (2011).

Western Australian government's decision to permit the shipping of lead through the port of Fremantle (Jones 2011). In this case, residents' lead poisoning fears can be sourced to lead spillage while being transported to and being loaded onto ships at Fremantle. The production itself takes place in Wiluna mine, approximately 950 km north-east of Perth.

With respect to lead poisoning in the city of Mount Isa, Taylor and Hudson-Edwards (2008, p.194) state, 'Given that the City of Mount Isa is directly adjacent to Mount Isa Mine and the City's principal drinking water storage area of Lake Moondarra is downstream of these, elevated concentrations of metals in the river system and in soils and sediments around the urban area might be problematic'. Their fieldwork involving testing soil samples has shown that lead and other heavy metal concentrations were above the standard levels. They state, 'The data demonstrate that the Mount Isa Mine is the primary source of sediment-associated metals' (p.198). In addition to lead pollution affecting water sources and soils, lead can also be dispersed in the atmosphere in gaseous form (see, for example, Mukai *et al*. 1993).

In addition to lead poisoning, other pollutants arising from mining activity in the city of Mount Isa are also known to affect its residents (see, for example, Munksgaard *et al*. 2010). As mentioned earlier, the city of Mount Isa, apart from being a major producer of lead, is also a major producer of copper, zinc and silver and is Australia's largest atmospheric emitter of sulphur dioxide, lead and other metals (National Pollution Inventory, 2009). As the Medical Journal of Australia (Munksgaard *et al*. 2010, p.131) editorial states, 'Research commissioned during a Queensland government-led inquiry a decade ago, as well as subsequent peer-reviewed studies, have unequivocally demonstrated widespread contamination of soil and airborne dust in an around Mount Isa, as a result of both historic and ongoing mining and smelting activity'. The contaminants referred to include lead, copper and other metals and metalloids (Munksgaard *et al*. 2010).

However, it is lead poisoning that has captured the most attention, especially in recent years (see, for example, Munksgaard *et al*. 2010). As the Medical Journal of Australia review concludes, 'The evidence is clear. There is a single primary source of environmental lead in Mount Isa: the historic and ongoing mining and smelting activity. Acceptance of this patent fact by all stakeholders will lead to a more targeted remedy to the lead problem, and better health and environmental outcomes for the community of Mount Isa'. This study examines the impact of such negative externalities on nearby property (house) prices within an approximately 4 km radius of the lead-smelting site (see Figure 1). This distance is selected based on the epidemiological work conducted by Landrigan *et al*. (1975). More details on this are provided later.

## 3. Literature review

A large number of HP price studies have been conducted to demonstrate how various factors influence property (house) prices. This review provides only a brief examination of the relevant literature to the present analysis. Rosen (1974) was the first to provide a theoretical explanation of HP price studies, and Freeman (1979) listed environmental attributes amongst other characteristics in measuring people's WTP for housing with different attributes. In other HP price studies, it has been shown that the negative externalities generated from an environmental disamenity on residential properties can be measured using a distance-based approach (see, for example, Nelson 1982; Palmquist and Smith 2002; Wisinger 2006; Samarasinghe and Sharp 2010).

According to the relevant literature (see, for example, Palmquist and Smith 2002; Lewis *et al*. 2008; Pope 2008; Tapsuwan *et al*. 2009; Samarasinghe and Sharp 2010; Mahmoudi *et al*. 2012), the HP price approach is an ideal and a powerful tool that could be used to assess property prices in relation to certain characteristics, such as environmental quality (disamenities), neighbourhood and structural characteristics. There are several characteristics that effectively determine property prices. These factors include the number of bathrooms, number of bedrooms, size of the house, age of the house, distance to environmental amenities or disamenities, distance to supermarket, distance to school, distance to the central business district and level of income. A large number of studies have used the HP price approach to capture the price of environmental quality/amenity through property (house) sales prices (see, for example, Pearson *et al*. 2002; Pope 2008; Hodgkinson and Valadkhani 2009; Tapsuwan *et al*. 2009). The extensive use of this approach is indicative of its acceptance in measuring the impact of externalities in environmental valuation studies.

A literature search conducted for this study shows that papers examining the impact of lead poisoning on property (house) prices are limited. There is one paper that specifically examines the impact of lead pollution on property (house) prices in Anniston, Alabama, USA, because of the presence of an Army depot. An HP price study is undertaken, which shows that lead cleanup was likely to increase property prices by US$1140 per household. The paper also shows that living 1 km closer to the polluting site reduces property prices by approximately two per cent (Affuso *et al*. 2010). Apart from this study, it is not easy to find any published literature that examines the impact of lead levels on property (house) prices. There are several newspaper articles that mention the likely impact of lead poisoning on property prices (see, for example, Anonymous 2009).

Although HP studies relating to lead poisoning are limited, several studies have been conducted to examine the impact of several hazardous chemicals (and sites) on property prices. For example, Simons *et al*. (1999) examined the effect of leaking underground storage tanks from gas stations in Ohio and showed that these gas leaks reduced the sale price of properties in the vicinity by 28–42 per cent. Wisinger (2006) showed in his PhD thesis that hazardous waste disposal sites do have a negative impact on nearby property prices. This analysis took into account the distance from the waste disposal site to a particular property. The study showed a positive relationship with property prices when distance increased. Mundy (1992), too, had earlier provided supportive evidence to this effect. In a more recent study, Kiel and Williams (2007), using a meta-analysis approach to examine what factors contribute to a decrease in property prices because of Superfund sites (a name given to the environmental programme established to address abandoned hazardous waste sites in the United States), showed that Superfund sites do negatively impact on property prices. However, they also show that in some cases, there is either no impact or a positive impact on local property prices.

Air pollution, too, is known to have an impact on property prices. There are many HP studies, especially in the United States, that show such an effect. The first two HP studies that were published (see Ridker 1967; Ridker and Henning 1967) estimated the association between housing prices and air pollution. Ridker and Henning (1967) studied the relationship between air pollution (sulphate levels) and variation in property prices in Illinois and Missouri, USA. According to their findings, property price differences disappeared when air pollution was reduced. Kim *et al.* (2003), too, showed in their study that property prices increased when pollution (sulphur dioxide and nitrogen oxide) decreased.

Smith and Ju-Chin (1995) reviewed 37 published studies to verify the relationship between air pollution (particulate matter) and property prices and provided 86 estimates for the marginal WTP for such pollution. Their findings showed that 'there is a consistent relationship between these measures of incremental values of reducing air pollution and the level of air pollution in each city…..'(p.210). They also stated that HP models have been successful in establishing a strong relationship between air quality conditions within a city at different residential sites and house prices. Chay and Greenstone (2005) examined the impact of air pollution reductions brought about by the US Clean Air Act Amendments of 1970 on property prices. They showed that decreases in air pollution (suspended particulates) were related to increases in housing prices during the 1970s. The study showed that a 1 $\mu g/m^3$ reduction in suspended particulates resulted in a 0.2–0.4 per cent increase in mean housing prices.

As mentioned earlier, environmental amenities in the neighbourhood such as recreational parks/green space, too, have an influence on property prices. Tyrväinen (1997) showed the positive impact of urban forests on nearby property prices using apartment sales data (1006 apartments) in Joensun, a town of 48 000 inhabitants in North Carelia, Finland. Benson *et al.* (1998) estimated the price of a 'view' amenity in a single real estate market in Bellingham, Washington. They concluded that the WTP for the visual amenity of an ocean view of 'high-quality' scenic value would increase the property price by 60 per cent and that the lowest quality of scenic value would increase the property price by eight per cent.

Shultz and King (2001) showed that proximity to large protected natural areas, golf courses, class II wildlife habitats and percentage of vacant land were positively related to increased prices. Nicholls and Crompton (2005) studied the effects of green belts on property prices and saleability. They found that while no negative impacts were generated by the existence of green belts, they could be neutral or positive.

Other neighbourhood attributes such as distance to schools, supermarkets and public amenities such as transport are known to have an impact on property prices (see, for example, Fraser and Spencer 1998). A variable we use in our study is distance to school. Downes and Zabel (2002) used the impact of school characteristics on property prices using data for Chicago during the period 1987–1991. They assigned to each house a school and found that school performance (i.e. test scores) had a significant impact on house prices. On the other hand, Fraser and Spencer (1998) in their study examining the impact of ocean views on the price of undeveloped residential land in Western

Australia found that the coefficient of distance to school was positive. On the other hand, major transport infrastructure that generates pollution and noise is known to have a negative impact on house prices. Bowes and Ihlanfeldt (2001) examined the direct and indirect effects of transit stations on the attractiveness of nearby neighbourhoods. This study showed that when the households are situated farther from a highway and a railway station, the property prices increased. The increase in property prices is not significant within the first half to 1 km contour ring, but is significant for the second and third kilometre contour rings. The marginal property price increase from a highway and a rail transit per unit increase in distance were 7.7 per cent and 3.5 per cent, respectively.

According to the above literature review, it becomes clear that a large number of studies have been conducted using HP price studies to demonstrate the impact of environmental and neighbourhood/convenience attributes on property prices. However, to our knowledge, this is the first time there has been an investigation into the impact of mining- and smelting-related lead pollution on residential house prices. Therefore, this study contributes to an important and highly relevant topic in the HP price literature.

## 4. Data and the estimated model

For this study, we collected a sample of 300 property (house) transactions data from within a 4 km distance from the site of the Mount Isa lead smelter (see Figure 1). The 4 km distance was selected based on an epidemiological study by Landrigan *et al.* (1975), which is discussed later. There is more recent evidence to show that this is the case. For example, Reuer *et al.* (2012) showed that the largest impact from lead contamination is within the first 5 km distance from the source of the pollution. Regarding the smelting sites, it should be noted here that the copper smelter and the Incitec Pivot Acid Plant are also located close to the lead smelter (see Figure 1). Of the house sales data sample of 300, we were able to use only 284 observations covering 63 streets in 15 suburbs owing to missing data in some of the collected information. The data used in this study cover the period 2000–2010 and were obtained from several secondary data sources. The real estate data (including sale price and house attributes) were obtained from RPData (2011). The subscription-based RPData is widely used by property buyers in Australia, and it records all property sales transactions. It should be noted here that only single-family real estate transactions were recorded for this study. Any transaction that listed a relationship between a buyer and a seller or any government purchase of a property was disregarded. Also disregarded were properties with land size greater than half an acre (2000 $m^2$). This approach follows the study of Lewis *et al.* (2008), who showed that by removing larger lots, the problem of inadvertently capturing the prices of potentially developable sites is avoided.

The spatial data relating to distance were obtained from Google Maps, which could be freely accessed (Google Map, 2011). ABS (2006) census data were used for socioeconomic variables. The spatial variables measured using Google Maps were as follows: distance to the lead smelter, nearest state school, nearest supermarket and the nearest community park. These variables represent the locational importance of the property (house) in relation to the distance to amenities and disamenities. The distance to the lead smelter site was measured using the direct distance-measuring tool in Google Maps (Google Maps Labs). The use of a distance variable as a means of revealing negative externalities is common in HP studies (see, for example, Nelson 1982; McCluskey and Rausser 2001; Morancho 2003; Nicholls and Crompton 2005; Wisinger 2006; Pope 2008).

The number of bedrooms (Bedrooms) and bathrooms (Bathrooms) acts as a proxy for dimensions of the house, which may vary independently of land size. The number of carport spaces is deemed important because many households possess one or more automobiles. *Logsize* is simply the size of the entire property (land) and is measured in square metres. Distance to supermarkets, schools and parks represents access to community and commercial areas. While the proximity to supermarket is considered as a convenience measure, the proximity to park represents a recreational/aesthetic amenity. Hence, the hypothesis is that when distance to these amenities increases, the property prices decrease. The hypothesis with respect to distance to school is likely to be the same if the demand for the school in the neighbourhood is high. For example, as discussed in the literature review, Downes and Zabel (2002) used the impact of school characteristics on property prices using data for Chicago during the period 1987–1991 and showed that school performance (i.e. test scores) had a significant impact on house prices. In such a case, when the distance to school increases, property prices decrease. However, in places where there is less competition for school entrance, this effect may not be present. Hence, the coefficient sign could be positive. Fraser and Spencer's (1998) HP price study conducted in Western Australia showed such a relationship.

To assess the effects of mining- and smelting-related pollution on residential house prices, the distance from the lead-smelting site to properties (houses) within a 4 km distance (*Distance*) was included in the study. This is an important variable in this study. This is because it is hypothesised that those properties that are closer to the lead smelter have lower property (house) prices than those that are farther away. The dummy variables for year of sale (D_2004, D_2005, D_2006, D_2007, D_2008, D_2009 and D_2010) are designed to capture any time trend in the housing market during this period. Any sales occurring between 2000 and 2003 are excluded for identification purposes. Data between 2000 and 2003 are used as the base year data to compare whether the property prices in other years are different. We used the period 2000–2003 as the base as there are only a few observations for a given year during this period in our sample. This is mainly because some of the sales transactions had missing data on house characteristics. The definition of the variables and their expected signs are shown in Table 1.

**Table 1** The definitions of independent variables used in the hedonic property prices study and their expected signs

| Variable | Description | Expected sign |
|---|---|---|
| Bedrooms | Number of bedrooms | + |
| Bathrooms | Number of bathrooms | + |
| Carport | Number of carports | + |
| Logschool | Log distance to the nearest state school (km) | −/+ |
| Logsupermar | Log distance to the nearest Coles supermarket (km) | − |
| Park | Distance to the nearest recreational park (km) | − |
| *Distance* | Distance to the mining and smelting sites | + |
| *Logsize* | Log size of the land (square metres) | + |
| Mhiwk | Median suburb income (Aus$/week) | + |
| D_2004 | Dummy; 1 if year of sale is 2004 and 0 otherwise | +/− |
| D_2005 | Dummy; 1 if year of sale is 2005 and 0 otherwise | + |
| D_2006 | Dummy; 1 if year of sale is 2006 and 0 otherwise | + |
| D_2007 | Dummy; 1 if year of sale is 2007 and 0 otherwise | + |
| D_2008 | Dummy; 1 if year of sale is 2008 and 0 otherwise | + |
| D_2009 | Dummy; 1 if year of sale is 2009 and 0 otherwise | + |
| D_2010 | Dummy; 1 if year of sale is 2010 and 0 otherwise | + |
| DSEC_2005 | Dummy; 1 if year of sale is during 2006–2010 and 0 if year of sale was during the period 2000–2005 | + |

Note: The variable 'DSEC_2005' was added to distinguish price fluctuations before and after 2005.

Several econometric issues and problems arise in the estimation of the hedonic models (see, for example, Cassel and Mendelsohn 1985; Huh and Kwak 1997). For example, the theory provides little assistance in specifying the functional form of the hedonic equation, which, however, is known to influence implicit prices. The different functional forms such as linear, log-linear and log-log have been used in previous studies. However, there is no evidence to show that one functional form is better than the rest. Cassel and Mendelsohn (1985) suggested that the estimates of the coefficient of environmental variable may be more reliable with simple functional forms. Palmquist (1991) argued that because the environmental variable plays a secondary role in determining housing prices, complex mathematical transformation might result in less accurate parameter estimates. We tested the results of different functional forms in the present study. The following equation was found to provide better results. Accordingly, the model that is used to analyse the determinants of property prices is given by Equation (2) based on the general matrix form shown in Equation (1):

$$\mathrm{Ln(y)} = X\beta + u \tag{1}$$

$$\begin{aligned}\mathrm{Ln}_{\mathrm{cpiprice}} = \; & \beta_0 + \beta_1\,\mathrm{Bedrooms} + \beta_2\mathrm{Bathrooms} + \beta_3\mathrm{Carport} + \beta_4\mathrm{Logschool} \\ & + \beta_5\mathrm{Logsupermar} + \beta_6\mathrm{Park} + \beta_7 \mathit{Distance} + \beta_8 \mathit{Logsize} + \beta_9\mathrm{mhiwk} \\ & + \beta_{10}D_{2004} + \beta_{11}D_{2005} + \beta_{12}D_{2006} + \beta_{13}D_{2007} + \beta_{14}D_{2008} + \beta_{15}D_{2009} \\ & + \beta_{16}D_{2010} + \varepsilon \end{aligned} \tag{2}$$

The dependent variable (sales price) has been adjusted for inflation using 2000 as the base year. Initially, ordinary least squares (OLS) and geographically weighted regression (GWR) models were estimated. GWR is an auxiliary regression that checks for the robustness of the spatial models used in this study. GWR is similar to the other spatial models where the data points are measured across Cartesian coordinates using the converted geographical coordinates. However, unlike in the spatial autoregressive (SAR) and the spatial error model (SEM), in GWR, the spatially distributed observations are weighted across Cartesian coordinate points through 'north and east' (Brunsdon *et al.* 1996). Hence, the GWR estimates are less reliable as it does not consider the inverse distance relationship, and the dependent variable is not weighted using a specific spatial weight matrix. This does not provide spatial dependence parameters as it is done in SAR and SEM.

The OLS and GWR models were followed by SAR and SEM models. This is because as shown by Anselin (1988) spatial dependence is one of the main consequences of using geographical data, especially when the properties are located close to each other. This spatial dependence occurs when the price of a property located in a particular suburb is determined both by its own characteristics and by the characteristics of nearby properties as well. Interestingly, until recently, not many papers have tested for spatial dependence (German *et al.* 2010). Some of the recent studies that have accounted for spatial dependence include Kim *et al.* (2003), Anselin and Lozano-Gracia (2009) and German *et al.* (2010).

Moran's $I$ statistic is used to provide proof of spatial dependence, which takes into account the level of spatial clustering or dispersion patterns. Moran's $I$ statistic ranges between $-1$ and $+1$, where $-1$ implies extreme negative spatial dependence (aggregation of dissimilar prices) and $+1$ implies extreme positive spatial dependence (clustering of similar prices). It is calculated using property prices, and for this study, it shows the presence of spatial dependence (clustering of similar prices). Moran's $I$ is estimated using the following equation:

$$\text{Moran's}\, I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n} w_{ij}(y_i-\bar{y})(y_j-\bar{y})}{\sum_{i=1}^{n}(y_i-\bar{y})^2\left(\sum\sum_{i\neq j} w_{ij}\right)} \tag{3}$$

In Equation (3), $y_i$ is the property price and $\bar{y}$ is its mean value. $W$ is the spatial weight matrix that is used in the SAR and SEM models in Equations (4) and (5).

We follow the spatial expression below in estimating the SAR and SEM models to correct for spatial dependence/autocorrelation. Equations (4) and (5) give the matrix representation of the general models, respectively. In this, $Z$ is the dependent variable (i.e. Price) and $X$ is a vector of independent variables. $\beta$'s are coefficients to be estimated, and $\rho$ and $\lambda$ are the spatial dependence parameters.

$$Z_L = \rho W Z_{L-i} + X\beta + u \quad (4)$$

$$u = \lambda W u + v \quad (5)$$

In Equation (4), $Z_L$ is the price of the property in location $L$ which is analogous to $y$ in Equation (1) and $Z_{L-i}$ is the lag price of the adjacent locations where $i = 2, \ldots n$. In Equation (5), $u$ is the spatially autocorrelated error term from Equation (1). $W$ has the properties of being row-standardised and symmetric and is an inverse distance weight matrix.

Failing to include this lag price/autocorrelated error variable as an independent predictor has a significant impact on the model specification when spatial dependence/spatial autocorrelation is present (Moran's $I$ is significant). The next section shows the results for the estimated models using OLS, GWR, SAR and SEM.

## 5. Results and discussion

Table 2 presents the descriptive statistics of all variables in our empirical analysis. Variables such as price, distance to school, distance to supermarket and the size of the land have been transformed into logs in the models. These variables have been transformed to obtain the correct functional form (see, for example, Wooldridge 2009, p. 43).

Although GWR accounts for robust estimation of the spatial models, spatial models (SAR and SEM) with rigorous test statistics are preferred for better interpretation of results. Of the two models, we select the SAR model for the interpretation of the coefficients. This is based on the robust Lagrange multiplier tests shown in Table 3.

Table 4 shows the regression results for OLS and GWR, and Table 5 shows the regression results for SAR and SEM. As can be seen, the results of the four models are similar for most of the variables used in the analysis and all the variables have the same signs. The OLS results show that the model explains about 78 per cent of the variation in property prices, and the GWR also shows similar results.

Most of the variables are significant at one per cent level. However, of the neighbourhood characteristics, the suburb median household income is not significant in all the four models. One possible reason for this could be the limited variation in data available for the variable median household income (Mhiwk).

As mentioned earlier, we use dummy variables for the 'year of sale' to capture the temporal variation in property prices. Our focus in this study is on the *Distance* variable, which captures the effects of mining- and smelting-related pollution on property prices. A priori expectation for the *Distance* variable is that it should correspond positively to the property prices in such a way that when the residential properties are located away from the

**Table 2** The descriptive statistics of the selected variables

| Variable | Mean | Standard deviation | Minimum | Maximum |
|---|---|---|---|---|
| Consumer price index price | 200 237.2 | 73 949.88 | 42 795.96 | 437 561.3 |
| Bedrooms | 3.17 | 0.70 | 1.00 | 6.00 |
| Carport | 0.86 | 0.90 | 0.00 | 6.00 |
| Bathrooms | 1.13 | 0.40 | 1.00 | 4.00 |
| *Distance* | 1.94 | 0.76 | 0.09 | 3.50 |
| School | 1.80 | 0.84 | 0.10 | 4.30 |
| Supermarket | 1.59 | 0.66 | 0.04 | 3.10 |
| Park | 0.40 | 0.19 | 0.06 | 1.50 |
| Size | 827.25 | 167.87 | 504.00 | 1556.00 |
| Mhiwk | 1544.00 | 242.95 | 611.80 | 1921.80 |
| d_2004 | 0.10 | 0.31 | 0.00 | 1.00 |
| d_2005 | 0.16 | 0.37 | 0.00 | 1.00 |
| d_2006 | 0.13 | 0.33 | 0.00 | 1.00 |
| d_2007 | 0.18 | 0.38 | 0.00 | 1.00 |
| d_2008 | 0.10 | 0.30 | 0.00 | 1.00 |
| d_2009 | 0.13 | 0.34 | 0.00 | 1.00 |
| d_2010 | 0.11 | 0.32 | 0.00 | 1.00 |
| dsec_2005 | 0.64 | 0.47 | 0.00 | 1.00 |

Note: More details about the definition of each variable are given in Table 1.

**Table 3** Robust Lagrange multiplier tests

| Test | Statistic | *P*-value |
|---|---|---|
| LM error (SEM) | 0.6 | 0.43 |
| Robust LM error (SEM) | 1.07 | 0.30 |
| LM lag (SAR) | 6.34 | 0.01 |
| Robust LM lag (SAR) | 6.80 | 0.00 |

pollution source, the prices tend to increase with the distance. This is because the dispersion of the pollutants in the air and soil tends to reduce with the increased distance. The marginal willingness to pay (MWTP) for being away from the source of pollution is AUS$ 13 947 per kilometre within the 4 km radius selected for this study. This is a 0.7 per cent reduction when compared to the OLS estimation. The MWTP was estimated at the mean distance based on the reduced-form functional relationship shown in Equation (6) for the selected spatial lag for the interpretation of coefficients based on the study of Kim *et al*. (2003).

$$Z = [I - \rho W]^{-1} X\beta + v \tag{6}$$

where $[I - \rho W]^{-1}$ is an $n \times n$ inverse matrix. The marginal implicit price of the spatial lag model is $\partial Z/\partial X' = \beta[I - \rho W]^{-1}$.

Landrigan *et al*. (1975) in an epidemiological study observed that the blood lead concentration levels of residents were highest when the properties were

**Table 4** The regression results of ordinary least squares (OLS) I, OLS II and geographically weighted regression (GWR)

| Variables | OLS I | | OLS II | | GWR | |
|---|---|---|---|---|---|---|
| | Coefficient | *t*-value | Coefficient | *t*-value | Coefficient | *t*-value |
| Bedrooms | 0.077*** | 3.81 | 0.043* | 1.83 | 0.077*** | 3.81 |
| Carport | 0.029** | 2.07 | 0.0367** | 2.16 | 0.029** | 2.07 |
| Bathrooms | 0.163*** | 4.73 | 0.169*** | 4.13 | 0.163*** | 4.73 |
| *Distance* | 0.069*** | 3.5 | 0.064*** | 2.71 | 0.069*** | 3.5 |
| Logschool | 0.075 | 0.9 | 0.052 | 0.52 | 0.075 | 0.9 |
| Logsupermar | −0.014 | −0.27 | −0.014 | −0.23 | −0.014 | −0.27 |
| Park | −0.125* | −1.77 | −0.057 | −0.69 | −0.125* | −1.77 |
| *Logsize* | 0.659*** | 4.06 | 0.552*** | 2.88 | 0.659*** | 4.06 |
| Mhiwk | 0.000 | 0.55 | 0.000 | 0.6 | 3.99E−05 | 0.55 |
| d_2004 | −0.010 | −0.19 | – | – | −0.010 | −0.19 |
| d_2005 | 0.316*** | 6.06 | – | – | 0.316*** | 6.06 |
| d_2006 | 0.592*** | 10.78 | – | – | 0.592*** | 10.78 |
| d_2007 | 0.915*** | 17.77 | – | – | 0.915*** | 17.77 |
| d_2008 | 0.961*** | 16.7 | – | – | 0.961*** | 16.7 |
| d_2009 | 0.854*** | 15.61 | – | – | 0.854*** | 15.61 |
| d_2010 | 0.846*** | 15.13 | – | – | 0.846*** | 15.13 |
| dsec_2005 | – | – | 0.690*** | 22.28 | – | – |
| $R^2$ | 0.779 | – | 0.67 | – | 0.779 | – |
| Adj. $R^2$ | 0.766 | – | 0.66 | – | 0.765 | – |
| Moran's *I* | 0.03** | 2.28 | – | – | −0.003 | −0.21 |

Note: ***, ** and * denote significant variables under 1, 5 and 10 per cent levels of significance, respectively.

located within a 1.6 km distance of the source of pollution. They also showed that at a distance of 6.6 km, the effect was non-lethal. The distance selected for our study is based on this evidence, and a more recent study by Reuer *et al*. (2012) showed a similar effect where the main effect was within a 5 km distance band.

The structural characteristics have the expected signs as they tend to increase property prices. As expected, structural characteristics such as number of bedrooms, bathrooms and carports have significant impacts on property prices. The coefficients of Bedroom*s* and Bathrooms are significant at one per cent level of significance, and the Carport variable is significant at the five per cent level. The variable *Logsize* is significant and is positive as per the a priori expectation. Distance to supermarket and recreational park variables have the expected signs as hypothesised. However, the distance to supermarket variable is statistically insignificant. The distance to school variable has a positive sign, but is also statistically insignificant. Fraser and Spencer (1998), too, find such a relationship. The purpose of using sales year dummy variables as mentioned earlier was to capture the temporal fluctuations of property prices. The results show that property (house) prices increased during the mid-2000s. In 2009, prices declined and were stabilising in 2010. This is most likely related to prevailing market conditions in the property market during this time rather than because of any pollution-related information becoming

**Table 5** The regression results for spatial autoregressive (SAR) and spatial error (SEM) models

| Variables | SEM | | SAR | |
|---|---|---|---|---|
| | Coefficient | *t*-value | Coefficient | *t*-value |
| Bedrooms | 0.075*** | 3.82 | 0.074*** | 3.82 |
| Carport | 0.031** | 2.27 | 0.032*** | 2.35 |
| Bathrooms | 0.160*** | 4.78 | 0.165*** | 4.99 |
| Distance | 0.067*** | 3.19 | 0.062*** | 3.23 |
| Logschool | 0.077 | 0.91 | 0.072 | 0.9 |
| Logsupermar | −0.019 | −0.36 | −0.011 | −0.22 |
| Park | −0.128* | −1.79 | −0.123* | −1.82 |
| Logsize | 0.626** | 3.78 | 0.603*** | 3.86 |
| Mhiwk | 4.05E−05 | 0.54 | 2.73E−05 | 0.39 |
| d_2004 | −0.003 | −0.06 | −0.017 | −0.31 |
| d_2005 | 0.320*** | 6.38 | 0.312*** | 6.28 |
| d_2006 | 0.591*** | 11.17 | 0.587*** | 11.19 |
| d_2007 | 0.914*** | 18.28 | 0.904*** | 18.33 |
| d_2008 | 0.962*** | 17.34 | 0.953*** | 17.3 |
| d_2009 | 0.845*** | 15.86 | 0.835*** | 15.85 |
| d_2010 | 0.847*** | 15.71 | 0.841*** | 15.76 |
| $R^2$ | N/A | – | N/A | – |
| Adj. $R^2$ | N/A | – | N/A | – |
| Moran's *I* | – | – | −0.007 | −0.219 |
| $\lambda/\rho$ | 0.09 | 1.11 | 0.11*** | 2.68 |
| Wald test ($\rho = 0$) $\chi^2$ | 1.22 (0.268) | – | 7.18*** (0.00) | – |
| LR test ($\rho = 0$) $\chi^2$ | 1.20 (0.271) | – | 7.04***(0.00) | – |

available to buyers. To demonstrate that the overall decline in property prices within the study area in the later part of 2000 was attributable to more information becoming available to buyers about lead poisoning is difficult without undertaking a field survey of residents. A dummy variable was used, separating time periods (2000–2005 and 2006–2010) shown in model 2 (*OLS II*) in Table 4. The results show that there is no decline in property prices during the period 2006–2010. However, all the regression models (Tables 4 and 5) clearly show that properties (houses) that are located closer to the lead smelter have lower property (house) prices than those that are located farther away. This is shown by the distance variable.

## 6. Conclusions

As discussed, HP price studies show that the price of a property (house) is related to a number of factors such as the characteristics of the property, attributes of the neighbourhood and environmental characteristics. These attributes influence property prices. They can have either a positive or a negative effect on house prices. The expectation is that different attributes or characteristics will produce differences in property prices and that pollution (e.g. lead) resulting from mining and smelting is also likely to have a negative impact on property prices. This was revealed in the literature review undertaken for this study. As discussed, this study used an HP price study to determine whether such a relationship also exists in the case of Mount Isa where many studies have shown that the level of pollution – and especially that of lead – is high, particularly in areas close to where the mining and smelting activities occur. In addition, the health effects of pollution, especially lead, have been reported in the local and national media (Cartwright 2010; Ryder 2010; Ryder 2011). Hence, the community of the city of Mount Isa has become aware of the problems arising from pollution. We, therefore, hypothesised that properties closer to the source of pollution are likely to have lower property prices than those that are farther away. The OLS I, OLSII, GWR, SEM and SAR models show that this is the case and is significant at the one per cent level. All structural variables and distance to park are statistically significant in all the three models. Most variables are significant at one per cent level. The results are consistent with other HP studies conducted relating to environmental externalities (see, for example, Hamilton and Schwann 1995; Tyrväinen 1997; Sirmans *et al.* 2005).

There are a number of important policy implications stemming from the regression results. The literature review also showed the prevalence of health impacts on residents, especially children. These are persuasive reasons for relocating residential and public utilities away from the mining-related activities. In terms of land availability, such an exercise would appear to be feasible given the size of the district and its small population. The key issue of course relates to the cost of relocation. However, given the sizeable incomes generated from mining activities and the longevity of these mines, the costs should be within the means of the stakeholders involved. The political will to act by relevant authorities should be based on a careful cost-benefit analysis based not only on health issues but also, as this study shows, on property prices as well.

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