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Quantifying changes in risk perception through house price differentials following the catastrophic Canterbury earthquake event

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ABSTRACT
Studies of risk perception across multiple disciplines conclude similar findings, one of which is that the perceived risk of extreme and rare events, such as earthquakes, is underestimated before the event and overestimated after the event occurs. This paper examines whether this change in risk perception is detected in price differentials for housing. A Difference-in-Difference (DID) model is used to model the events utilizing control and treatment variables to estimate price determinants. The findings indicate that after the 22 February 2011 Canterbury earthquake consumers' are paying premiums of 15.1, 18.8 and 16.1% to live on no risk, low risk and medium risk land, respectively, compared to high risk zoned land. This supports the hypothesis that consumers' perception of risk became more acute after experiencing an extreme event. Risk premiums associated with safer land zones are not evident in the coefficients for control variables implying there was no accounting for land risk before the earthquakes.

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Introduction

This paper examines the impact of the Canterbury earthquakes on house prices. Changes in perceptions of risk following a significant and rare natural disaster should be evident from house price differentials. Compared with previous studies, this papers contribution is as follows. Firstly, the study area is unique in several ways. The geographic area under study consists of a property market:

- where market participants had no previous experience of significant and localised earthquakes occurring,
- where the fault lines were never identified previous to their rupture,
- with a high level of earthquake insurance that possibly mitigates any risk,
- where the Government offered compensation to approximately 6000 households which created a supply shortage and extra demand,
- where the land hazard mapping was updated and changed after the earthquakes.

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Secondly, many previous studies do not examine an actual event but instead examine the impact of new hazard information about natural hazards on house prices. This study examines the before and after impacts of an actual earthquake event and is a quasi - natural experiment that offers a robust method for estimation of the effects of natural disasters. Thirdly, some studies utilise survey data and quoted rather than transacted price data. All data used in this study are derived from actual sales transactions as well as other official information.

This study's findings are important for participants in the property market and authorities responsible for the dissemination of information on natural hazard risk.

Specifically, this paper will identify whether risk perception, and the pricing of housing, has changed given a recently experienced extreme and rare event. Are subjective assessments of risk capitalized into house prices or are they ignored, particularly the risks associated with rare natural events? When these rare natural events occur, do they abruptly change those perceptions of risk? If so, they will leave an imprint on house prices and provide a means to detect changing perceptions of risk. This will be conducted by developing a hedonic model of the determination of house prices and formulate econometric versions of this model that allow testing of the hypothesis about possible optimisation of risk into house prices.

Proponents of the efficient housing markets hypothesis argue that all publicly available information (including that on risks) will be incorporated into market price differentials. Quantitative modelling of house prices should then reveal risk related differentials even before natural events occur. But we know that people at best exhibit bounded rationality. Bounded rationality is the concept that individuals decision-making is limited by the information they have, their cognitive ability and the amount of time they have to make a decision. With rare events it may be sensible to ignore the risk even though the results of such an event could be cataclysmic.

Therefore the principal research questions to be examined in this paper are:

(1) Before the earthquakes did homeowners' perceive the risks so that high risk properties sold at a discount as compared to low or no risk properties all else equal?
(2) After the earthquake, did homeowners' show more awareness of risk such that risk-related house price differentials widened?

Background

The composition of the housing market under study includes 163,944 dwellings across three council territories that have a combined resident population of 424,935 . The territorial authority areas included in the study include Christchurch and neighbouring authorities of Waimakiriri and Selwyn districts. Christchurch is the most densely populated and comprises a mix of medium density inner city housing, suburban standalone housing and smaller units. Christchurch was also the most affected by liquefaction. Liquefaction is the land hazard referred to in this study. Selwyn and Waimakiriri districts contain a lot of rural land with pockets of suburban standalone housing and some smaller units. The sales transactions include residential sales only and not rural sales within Selwyn and Waimakiriri districts. Both these districts contain housing markets that are considered substitutable residential markets for Christchurch such as the townships of Rolleston, Lincoln, Kaiapoi and Rangiora.

Liquefaction of land is the process of sand and water mixing together beneath the ground during the shaking intensity of an earthquake. This results in heavy objects sinking and lighter objects rising. Most of the extreme damage to housing and infrastructure in Christchurch was caused by the liquefaction process rather than the shaking intensity of the earthquake itself. This land risk attribute was well documented prior to the earthquake to the extent that pre purchase Land Information Memorandums (LIM's) included references to it. A LIM report details any known hazards, such as liquefaction risk, as well as property information. They are produced by the relevant local authority using property file records, consent information and hazard information. If a purchaser's LIM report made reference to potential liquefaction risk they would then need to make further inquiries with the Regional Council, Environment Canterbury (ECan), to gather more information about the degree of liquefaction and land damage risk specific to the property they wished to purchase. There is no obligation on the purchaser to elicit this information should they choose not to.

On average, there are around 15,000 earthquakes in New Zealand every year. Most of these are small and not of sufficient size to be felt. However, the 7.1 magnitude Canterbury earthquake of 4 September 2010 occurred 40 km from the city of Christchurch, a metropolitan area containing a local resident population of 348,435 people. Major aftershock events greater than magnitude 6.0 followed, the most devastating of which occurred on 22 February 2011 and left behind collapsed buildings, 185 fatalities and significant property and infrastructure damage. To date, repair and replacement estimates total $40 billion NZD.[1] In terms of property damage, it is generally believed that the 22 February event was the most significant. Prior to 2010 a localised earthquake event that caused minor damage in Christchurch occurred in 1888. In that case the epicentre was 100 km north of Christchurch and the shaking toppled the Christchurch Cathedral's spire. No reports of liquefaction in Christchurch are revealed in the historic reports. The shaking intensity and ground speed on 22 February 2011 were at the extreme end of the Modified Mercali scale, a scale used by seismologists to inform planning and building standards.

The geology of Christchurch was identified early on in the city's history and is thoroughly depicted in the "Black Map" of 1856. This "Black Map" shows many swampy land areas across it. Indeed, it may be the first attempt at identifying land quality hazards for the purposes of planning the city of Christchurch. Today, most of these areas are now occupied by residential and commercial land uses, the swamps having been drained and the tributaries filled in long ago.

The majority of homeowners' had earthquake cover as part of their home and contents insurance. Parts of home owner insurance premiums also contribute to a Government earthquake fund which is drawn upon in the event of a major earthquake. There is a limit to the amount able to be withdrawn from the earthquake fund of $2 billion per event. The damage associated with the 22 February event resulted in government having to allocate further funds from the national budget.

Shortly after the first earthquake all sale and purchase contracts allowed for the transfer, from vendor to purchaser, of insurance claims for the repair and reinstatement of homes as well as the transfer of insurance policies themselves. Where the policies are inherited by new homeowners' and those homeowners' are indifferent about the inconvenience of making a claim, there should theoretically be no discount associated with earthquake risk. However, there is a risk that outstanding claims will not be fully meet.

However, there could be frictional barriers to selling in heavily damaged suburbs where a significant number of homes are physically uninhabitable and unable to be repaired quickly. In this case, a restricted level of habitable supply may have caused upward pressure on prices in those areas if local demand levels remained sufficient.

The land zoning and testing that has occurred post-earthquake is far more extensive than the pre earthquake land testing and zoning. Properties near the Avon River which travels through the city and eastern suburbs have experienced significant lateral spreading. In some areas the land has dropped up to 1.5 metres along its banks. At the same time, the river bed has risen creating new flood risks during spring tides for areas such as Bexley. So severe was the damage to land and housing that the New Zealand Government offered to acquire around 6000 houses in Christchurch and Kaiapoi that are sited in what has been categorised as the red zone; a zone with such poor land stability that it was deemed uneconomic to remediate. More recently another red zone has been announced for Port Hills for rock fall risk rather than liquefaction risk. The Port Hills are steep in places and housing developments in valley areas are susceptible to rock fall risk where craggy rock outcrops exist above them. Defining the danger area required substantial computer simulation and safe field tests to determine the likely trajectories given certain land features, ricochet and fragmentation of falling rocks.

The pre earthquake land liquefaction maps were constructed with the best information available at the time from a combination of historical records and core sampling. The reality is an actual event that is the best platform from which to develop the most accurate set of earthquake risk land maps. The regional council, Environment Canterbury, provide spatial distribution maps of pre earthquake liquefaction ground damage potential. There are three other similar versions of this map. The first of these maps illustrates the liquefaction potential only, but there are two versions of the map representing low water table and high water table scenarios. Similarly, there is also a liquefaction and land damage potential map with both low and high water table scenarios. Liquefaction and land damage under a high water table scenario is assumed to represent the worst case. This is the starting point for pre earthquake land zoning to be used to overlay property sales occurring prior to the new land hazard zone announcements.

New land liquefaction risk maps now vary significantly from the land hazard maps before the earthquake, and homeowners' that previously were located in low risk zones, or even no risk zones, may now find themselves in medium risk or high risk zones and vice versa.

Understanding how people perceive risk and what the factors are that make people, or communities, have more of an understanding of the real risk than others is an important aspect of this research. The body of knowledge on broader risk perception studies spans psychology, anthropology and sociology disciplines (Fischoff, Slovic, Lichtenstein, Read, & Combs, 1978; Slovic, Fischhoff, & Lichtenstein, 1981; Kleinhesselink & Rosa, 1991; Cekic & Yazici, 2011; Gaillard & Dibben, 2008). The common findings or themes from these broader risk perception studies can be summarised into four categories as follows:

(1) Peoples experience of extreme hazards matters

Those who have experienced the hazard before have a better understanding of the real risk and are better prepared to deal with the hazard. Similarly if people have not experienced the risk they will use their other experiences of different risks as benchmarks to assess risk.

(2) Risk perception depends on the individual

Sex, religion, culture, level of education, economic circumstances and ethnicity of individuals can influence their perception of risk. Therefore, a uniform approach to information dissemination about risk may not be appropriate amongst diverse populations.

(3) Physical and economic constraints may create trading-off for risk

People are willing to accept a level of risk when the options for living in safer areas are constrained by natural or man-made physical barriers, or elevated costs.

(4) Economic and social attachment to a location may create trade-offs for risk

Social connectedness to family and community, or distance to one's job may be overriding risk.

These broader risk perception studies support the view that consumer decision-making, when faced with information about risk, is complex. This suggests decision-making about risk, especially risks associated with extreme and rare events, may not meet the criteria of rational behaviour assumed by neoclassical economic models.

Literature review

Traditional neoclassical economic models of "efficient markets" assume market participants are fully informed, and can therefore assign a probability that accurately reflects the chances of a natural hazard (or other event) occurring. Prices in efficient markets will reflect these risk assessments.

Hedonic risk perception studies

The aim of risk perception studies that use price as the dependant variable is to capture price increment changes in response to an event occurring. This is typically done by including a dummy variable representing the events occurrence at a point in time, and a set of sales data for properties that transact before and after the event, associated amenity variables and other relevant spatial data. An important feature of some studies is sample design; by including property transactions that are exposed to different levels of risk it is possible to exploit these differences for estimation purposes. However, variations in methodology exist including different hedonic specifications. These methods have been applied to the impact of earthquake events on housing markets in US, Japanese and Turkish housing markets. Four studies examine the impact on house prices of land related hazard risk (Brookshire, Thayer, Tschirhart, & Schulze, 1985; Murdoch, Singh, & Thayer, 1993; Nakagawa, Saito, & Yamaga, 2007; Naoi, Seko, & Sumita, 2009). However, with the exception of Murdoch et al. (1993) all studies examine land risk variables as either safe versus unsafe damage zones, or earthquake probability zones rather than liquefaction risk category zones.

Brookshire et al. (1985) estimate two hedonic models for Los Angeles County and Bay Area Counties and discover a price gradient that reflects a premium for safer areas after the passing of a 1974 state law which made it mandatory for authorities to disclose earthquake hazard information. The land hazard referred to in the study is not land liquefaction risk but land zones based on distance to fault lines called Special Study Zones (SSZ). The SSZs are designated areas with elevated risk which is determined by recently active fault traces. Using a sample size of 4865 and 5438 for Los Angeles and Bay Area Counties regressions are estimated using site specific characteristic data, community characteristics and location characteristics as independent variables and transacted sales prices of owner-occupied single family residences as the dependent variable. The SSZ zone variable is included in the site specific data-set as a dichotomous dummy variable. If a house sale is located within the SSZ then the dummy variable is set to 1 or 0 otherwise. All house sales data relate to houses sold in 1978 after the passing of the state law. The study is limited to the impact of information about earthquake risk and does not extend to a study of before and after impacts of an earthquake event itself. The results show a significant negative relationship between the SSZ dummy and house prices. The discounts associated with living within the SSZ zones in Los Angeles and the Bay Area Counties were approximately 6% and 3% respectively, other things being held constant. They conclude that there is evidence of rational consumer behaviour in response to hazard information even without a recent earthquake event. Further support for this finding is derived by performing the same regression using 1974 data which, as expected, showed the SSZ dummy was insignificant. An interesting observation about earthquake insurance cover is that only 4% of the structures in Los Angeles were covered for earthquake damage at that time. Therefore, the discount on house prices within the SSZ zone can be viewed as an allowance for the cost of self-insurance. In this context the SSZ homeowners' would need to examine earthquake recurrence information to calculate the present value of future replacement or repair costs to determine the price discount. This self-insurance context is in contrast to Christchurch where the majority of homeowners' had earthquake cover included as part of their home and contents insurance package. Brookshire et al., also not that significant media reports and awareness of earthquakes existed in Los Angeles and public awareness was very high. Unfortunately, price impacts following an actual earthquake event are not examined in their study.

A US study that examines the impact of an actual earthquake event on mortgage defaults is conducted after the 1971 San Fernando earthquake (Anderson & Weinrobe, 1986). With lenders experiencing a number of losses from mortgagee sales Anderson and Weinrobe aimed to find out what factors explained why homeowners' went into default whilst others did not. A two stage analysis was done using, as the first stage, discriminant analysis and second stage regression estimations. Default/Non default is used as the dependant dummy variable. Using loan files from three savings and loans associations, a sample of 372 earthquake damaged properties was constructed made up of 124 mortgage defaults and 238 non mortgage defaults. Most of the defaults occurred with 12 months of the earthquake. Net equity of homeowners' after the earthquake is found to be the most significant factor causing default. Other factors include reduction in property value, relocation, divorce, financial problems and emotional problems post-quake. The implication of these findings are that mortgage default occurs for homeowners' with high debt ratios as property values after the earthquake decline thereby reducing homeowners' net equity to unsustainable levels. It is noted that none of the properties included in the sample had earthquake insurance and that it was not a requirement of lenders before granting mortgages. The study does not extend to an examination of property and site specific attributes, such as land hazard risk, or locational attributes.

One study examines land hazard risk in the form of soil quality effects on house prices after an actual earthquake. Murdoch et al. (1993) examine the impact of the 1989 Loma Prieta earthquake on housing in the San Francisco Bay area. Their data consist of 7102 records and include sales transactions of single family detached dwellings, an earthquake dummy (0 before the earthquake, 1 after the earthquake), soil type, property attributes and spatial attributes data and month of sale. They estimate a linear hedonic model to determine the influence of the variables on price. Various functional forms are estimated such as linear, log-linear and semi log to examine the robustness of estimates. They find that the earthquake dummy coefficient was negative and statistically significant indicating a price discount after the earthquake across their sample of 2%. Furthermore, they discover that for a one step improvement in soil category, the market premium is 2.5%. However, the researchers advise that this interpretation must be considered with caution as soil type categories do not follow a natural uniform scale. However, the specification of a Difference-in-Difference (DID) regression, which uses the interaction of an earthquake dummy with a soil type dummy within a treatment variable specification would have allowed for examination of changes in risk perception for differing soil types given a recent earthquake. Like Brookshire et al., (1985) they found the homes outside the SSZ zone are priced, on average, 3.7% higher than those within the SSZ zone.

(Nakagawa et al., 2007) examine the interaction between housing rents and earthquake resistant construction in Tokyo. In doing so they construct a regression equation utilising cross sectional property attribute data including construction information, earthquake zone probability and spatial attribute data. This is then regressed against rent. Rents are quoted rather than transacted rents. The study does not extend to an examination of changes in perception following an actual earthquake, but only a cross sectional, point in time, examination of rent determining attributes. Their model measures 90% of the variation in rents across Tokyo and they find a strong premium attached to those houses and units constructed to new earthquake and fire codes. Construction design may be endogenous in this study. This is a general issue associated with cross section designs. In addition they include land risk attributes in the form of earthquake probability zones. They find that the higher probability areas have a significantly negative impact on rents. However, bringing houses up to earthquake codes mitigates this effect.

Another Japanese study uses national housing panel data and a DID specification to model post-earthquake price discounting in Japan (Naoi et al., 2009). The data are derived from a survey with 4005 respondents. Rents are quoted prices rather than transacted prices and house value data are estimated from the survey respondents. They incorporate housing attribute, locational attributes and respondent statistics such as income, sex, age and employment type as well as city level earthquake risk probabilities into their model. Their results show that the post-earthquake dummy coefficient is negative and significant when regressed against price for both rent and house value models. Their treatment variable uses the probability of an earthquake in particular probability zones and a dummy variable set to 1 if the value is derived after the earthquake. The findings suggest that the homeowners' and renters' underestimated the earthquake risk before the earthquake and they became more risk averse after the earthquake as illustrated by discounting. The researchers conclude that households do not account for earthquake risk prior to an earthquake event but this significantly changes after an event.

As discussed in the introduction this study is unique in several aspects from those studies discussed above. It is a quasi-natural experiment that offers a robust method for estimation of the effects of natural disasters and all data are derived from actual sales transactions rather than survey derived or quoted price data.

Data

Property transactions

The original sales data-set are pooled and cross sectional and consists of 4901 residential transactions between 1 Feb 2007 and 31 October 2012. These transactions relate only to single standalone residential dwelling whose liquefaction hazard classification remains consistent before and after the earthquakes. This allows for the examination of changes in perception of risk after the earthquake events rather than the impact of a change in land classification. A larger sample of 29,974 sales transactions over the same period has also been GIS mapped and these represent sales whose liquefaction classification has changed after the 22 February 2011 earthquake. These sales will be used in a model in a subsequent study where both changes in risk perception following the earthquake combined with a change in risk classification is detected in house price differentials.

The benefit of pooled and cross-sectional data over a sales index is that it provides much more spatial variation and greater degrees of freedom. The sales data have been sourced from Headway Systems Limited who holds all sales data for New Zealand sales transactions. Only residential dwelling data are used, and rural sales, lifestyle block sales and commercial sales are excluded. The sales data-set includes, among other things, sale price, transaction date, condition rating, construction materials, land area, floor area, land title information and tenure type. It is important to note that the condition ratings exclude earthquake damage. Of these transactions, 24.6% occurred after the September 2010 earthquake. Transactions across three Territorial Authority (TA) areas of Christchurch City, Waimakiriri and Selwyn Districts are combined to create the data-set. Included within these three TAs are the main city of Christchurch, and satellite towns of Rolleston, Kaiapoi and Rangiora. These are all within a 40 min drive of Christchurch and are considered substitutable housing markets. They are described often as “Greater Christchurch” in long term land planning documents such as the 35 years Urban Development Strategy (UDS). Other TAs shown on the map are outside the study zone but their inclusion make up the combined province of Canterbury.

Figure 1 shows each territory boundary (white lines) within Canterbury (orange line).

Land hazard risk zones

The nomenclature varies between pre and post land hazard maps and Table A1 in the appendix shows how these variations have been grouped into common risk categories.

Figure A1 in the appendix shows the spatial distribution map of pre-earthquake liquefaction ground damage potential. There are three other similar versions of this map produced by ECan as previously mentioned. Figure 1 is assumed to represent the worst case; Liquefaction and land damage under a high water table scenario. This is the starting point for pre-earthquake land zoning to be used to overlay property sales that occurred prior to the new land zone announcements. As shown in Figure 1 large areas are recorded as uncertain but with a likely risk category assigned to them. This information is what prospective purchasers’ would need to decipher in order to make judgments about the risk, and take account of that risk in their decision-making process about price, among other things.

Figure A2 of the appendix shows a more comprehensive map of land hazard zones developed after the actual earthquake events. The uncertain areas apparent in Figure 1 are no longer uncertain. Furthermore, access to this information was made available from the Canterbury Earthquake Recovery Authority (CERA) website after the earthquakes where

Figure 1. Territorial authority boundaries. Source: LocalCouncils.govt.nz.

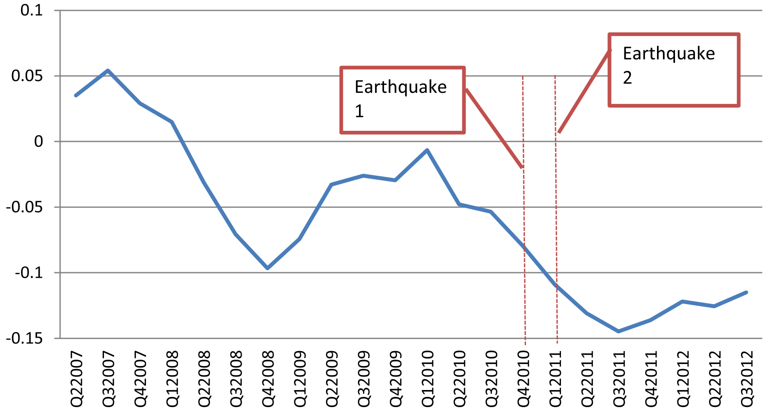

Figure 2. Quarterly time trend coefficients.

users can simply type in a property address and receive its hazard category. Prior to this prospective purchasers' would need to make an enquiry with ECan to obtain the information on specific properties should the LIM report mention a possible liquefaction risk. That process was much more inefficient in caparison to web based information.

Table 1 provides a list of independent variables, their definition and measurement. All continuous variables are converted to their natural logarithms.

Sample design

The sample contains 4901 transactions spanning 1 February 2007 to 31 October 2012 to provide approximately three and a half years of transactions prior to the first major earthquake

Table 1. Variable data list.

Variable category	Variable Name	Definition	Measurement
Property Attribute Data	Floor area	Dwelling size	Log of square metres
	Lot Size	Section size	Log of square metres
	Age	Age of dwelling categorised in decade bands	Dummy variable equal to 1 if age falls within decade band, 0 otherwise
	Condition	Observed condition of property excluding earthquake damage ranging from poor, fair or excellent	Dummy variable equal to 1 if condition grade falls within condition range, 0 otherwise
	Main construction material	Main construction cladding material	Dummy variable equal to 1 if cladding type falls within cladding option, 0 otherwise
Neighbourhood Attribute Data	Suburb group	Groups of suburbs fefined by QVNZ	Dummy variable equal to 1 for a sale occurring within suburb group, 0 otherwise
	Distance to CBD	Kilometres	Log of kilometre distance
	Public housing	Government owned affordable rental housing	Log of percentage of government housing relative to all housing within relevant statistical meshblock
Earthquake Attribute Data	Event(s) themselves	EQ1: Earthquake that occurred 4 September 2010 EQ2: Earthquake that occurred 22 February 2011	The event dummy for the September 2010 earthquake indicates all transactions that occurred after that event and before the second event.Dummy variable represented by 0 for a sale that occurred before EQ1 and 1 after the EQ1, then 0 after EQ2 Event dummy for the 22 February event indicates all transactions that took place after that event. Dummy variable represented by 0 for a sale before EQ2 and 1 for a sale after EQ2.
	Land hazard category	Four liquefaction of land potential categories included being no risk and unmapped zones, low risk, medium risk and high risk	Dummy variable represented by 1 for a sale that occurred in a particular zone, 0 otherwise

and two years of transactions after the first earthquake. The sample transactions were located geospatially using a New Zealand Street address GIS file in order to match addresses of sales to street addresses. Unfortunately the sales database land title information and the land title GIS files did not have a common identifier to link the sales to land parcels. Land liquefaction hazard GIS maps where then used to tag individual sales addresses to their land hazard category.

The sales transactions used for the dependent variable include single standalone residential houses and excludes rural sales. These sales have consistent land liquefaction categories before and after the earthquakes.

Three sales records were then removed from the 4901 sample as they had unrealistic floor area records of 40m^2 or less. The sample allows for the estimation of a regression model in which the land risk is constant before and after the earthquakes. The post-earthquake land risk coefficients represent inferences about changes in consumer risk perception given a heightened awareness of land risk after experiencing an earthquake. The sample is considered a sufficient and representative sample. Based on 164,000 households in the subject area the sample size of 4898 provides a 99% confidence level and a standard error of 2.

Table 2. Sales transaction volumes relative to earthquake events and land hazard category.

	Entire Sample	Before earthquake one	After earthquake one (4 September 2010) and before earthquake two	After earthquake two (22 February 2011)
No risk	655	477	33	146
Low risk	113	72	6	36
Medium risk	2920	2115	152	654
High risk	1210	1034	53	124
Totals	4898	3698	244	960

Table 3. Descriptive statistics for continuous variables.

Continuous variables	Count	Mean	Median	Maximum	Minimum	Standard deviation
Price	4898	368182.3	325000.0	1110000.0	149333.0	151586.2
Distance to CBD (Km)	4898	27.7	2.5	136.8	1.6	50.4
Land area (m^2)	4898	652.3	628.0	6069.0	128.0	241.0
Floor area (m^2)	4898	142.5	120.0	640.0	40.0	58.5
Public housing (percentage in meshblock)	4898	3.6%	0.0%	78.8%	0.0%	9.1%

Table 2 summarises the sales transactions before earthquakes one, between earthquakes one and two and after earthquakes two.

Descriptive statistics

Table 3 provides the descriptive statistics for continuous variables. The median sales price is $325,000 which varies from $149,333 to a maximum price of $1.11 million. The distance of each sale to the CBD averages 2.45 km and varies from 1.6 km to 136.77 km. Not all statistical meshblocks contain public housing. The maximum percentage of public housing in any meshblock is 77.78%, but the average is just 3.63%. A meshblock is defined as the smallest area in which statistical Census data is collected. They vary in size from a city block to large rural meshblocks. The floor areas and land area statistics are typical of urban residential sales characteristics.

Table A2 of appendix 1 provides a list of descriptive statistics for all indicator variables. Of particular note is the reduction of sales volumes after the first and second earthquakes. Most sales occur in the medium risk hazard category regardless of whether before, or after, first and second earthquakes. The dominant cladding type is wood (weatherboard) followed by brick.

In order to avoid perfect collinearity some of the dichotomous variables need to be omitted from the OLS estimation. Where this is done the omitted variable from the group becomes the reference category variable for coefficients comparison.

Methodology

Based on the ideas put forward by social psychologists from broader risk perception studies it is hypothesised that individuals who have experienced an extreme event, each with their own perception of risk, will price that risk along a price gradient for housing. The key hypothesis is that risk perception becomes more acute after a natural earthquake event and the premiums associated with low risk zones will increase after the event.

In order to systematically answer the research question a proposed Ordinary Least Squares (OLS) regression using a DID hedonic specification will examine the impact of earthquake(s) across different land zone categories on residential prices over the entire sales data period. This type of specification uses control and treatment variables with dummy variables representing the event itself which, in this case, is/are the earthquake event(s).

Model specification

Hedonic techniques have been used to determine the implicit prices associated with the attributes of differentiated products since Court (1939), Grilliches (1961) and Lancaster (1966). Rosen's (1974) work proposed a structure for the hedonic regression that suggested a procedure for the recovery of marginal willingness to pay functions for heterogeneous individuals. Equilibrium in the housing market is represented by price distributions that can be measured by a hedonic model. Despite the well-documented disadvantages of OLS regression it has become the tool of choice for a lot of asset property value hedonics and for the valuation of local public goods and environmental amenities. In a normal market, where no exogenous shock had occurred, the model would simply include property and location attributes to estimate the different price points. In this case where properties are exposed to a hazard then you would expect this to be reflected in prices regardless of whether the event had occurred. Therefore, the riskiness of alternative locations should be a variable in the model regardless of events occurring. Furthermore, and if an event does occur, transactions before and after the event need to be distinguished due to possible changes in risk perception. With this in mind we account for the exogenous shock by introducing earthquake risk attributes. In its simplest form, the following model is specified:

Equation 1 Simple form specification

$$P = f(\mathrm{S, L, E}) \tag{1}$$

where P = Price paid for property, S = Site specific property attributes, L = Location attributes, E = Earthquake hazard attributes.

Expanding the simple model into a DID specification results in the following hedonic model.

Equation 2 Expanded form DID specification

$$P_{it} = \alpha + \sum_k \beta_k C_{ik} + \sum_t \delta_t Q_{it} + \sum_m \lambda_m Z_{im} + \sum_x \varphi_x (Z * P1_{ix}) + \sum_y \phi_y (Z * P2_{iy}) + \varepsilon_{it}$$

where P_{it} = real price of residential sales i in period t = constant term, C_{ik} = a group of property and spatial attributes, Q_{it} = a set of quarterly time dummy variables with first quarter 2007, as base period, Z = a group of four land hazard zone variables where dummy variables represent an in-zone sale (1 in hazard zone sale, 0 outside hazard zone sale). $P1_{ix}$ = a dummy variable representing a sale occurring post-earthquake 1 (0 for sale occurring before, 1 for sale occurring after earthquake event but before earthquake 2). $P2_{iy}$ = a dummy variable representing a sale occurring post-earthquake 2 (0 for sale occurring before, 1 for sale occurring after the earthquake event) = error term.

The three land risk hazard variables are:

NO RISK
LOW RISK
MEDIUM RISK

The omitted variable is HIGH RISK and serves as the reference variable.

All continuous variables are converted to their natural logarithms. Appreciation or depreciation of house prices due to an earthquake is derived from examining the coefficients of the treatment interaction variables (Z*P1) and (Z*P2). Where perceived risk has increased after an earthquake, a significant and negative coefficient would be expected for higher risk land zones, but a positive coefficient is possible for all risk categories if the earthquakes result in a sharp contraction in supply that exceeds and slump in demand.

Results and analysis

The full OLS regression output is presented in full in Table A4 of the appendix. The Durbin–Watson test suggests a rejection of the null hypothesis of no autocorrelation in the residuals. A further autocorrelation test using the Breusch–Godfrey Serial Correlation LM test also confirms the presence of autocorrelation. The presence of autocorrelation means that the OLS estimate is not BLUE (Best Linear Unbiased Estimate) and the OLS standard error and tests statistics are not valid.

Furthermore, the Breusch-Pagan-Godfrey test for heteroskedasticity confirms that the null hypothesis of homoskedasticity should also be rejected. The presence of heteroskedasticity means that the OLS estimate is not efficient. Hence, the OLS is not BLUE. The variances in the OLS estimators are biased and the t-statistics and confidence intervals are not valid for interpreting inference.

There are several options for correcting both autocorrelation and heteroskedasticity such as finding and including omitted variables or specifying a different model. Newey and West (1987b) have proposed a more general covariance estimator that is consistent in the presence of both heteroskedasticity and autocorrelation of unknown form. Applying this method to the OLS estimate yields the following more robust estimation presented in Table 4. Note that the coefficients do not change from the original OLS estimate, but the standard errors and t-statistics have changed to more robust measures.

The excluded locality dummy SUBURB 1 (Aranui;Wainoni; Burwood;Avondale) was chosen as it was an area that was impacted heavily by the liquefaction process and is generally regarded as a lower socioeconomic area. Of the remaining localities 25 had positive and significant coefficients compared to the omitted dummy. Locality premiums range from 6.22% for SUBURB 28 (Shirley;Dallington;Avonside;Richmond) to 88.12% for SUBURB 10 (Fendalton). Only the control variable LOW RISK is significant, but its coefficient is negative implying a discount compared to the omitted HIGH RISK variable which is counter-intuitive. This suggests that consumers' did not account for liquefaction risk in their pricing for housing prior to the earthquakes. The negative coefficients for these land risk control variables may reflect a preference for location since the most established areas located closest to the CBD also comprise higher land risk zones in general.

EQ1 MEDIUM RISK is significant showing a premium of 5.0% compared to the omitted EQ1 HIGH RISK. The coefficients for EQ1 NO RISK and EQ1 LOW RISK are not significant and therefore no impact on prices is detected. Earthquake 1 was less damaging than earthquake 2 which explains this finding. Furthermore, Government announcements

Table 4. OLS regression output for equation 2.

Dependent Variable: LOG_PRICE

Method: Least Squares

Included observations: 4898

HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 10.0000)

Variable	Coefficient	Std. Error	*t*-Statistic	Prob.
CONSTANT	9.003708*	0.069017	130.4561	0
LAND AREA (LOG)	0.146032*	0.011739	12.43994	0
FLOOR AREA (LOG)	0.536583*	0.01458	36.80329	0
NO_RISK	−0.017728*	0.011222	−1.579801	0.1142
LOW_RISK	−0.054476*	0.020695	−2.632365	0.0085
MEDIUM_RISK	−0.000719*	0.008175	−0.088007	0.9299
Q22007	0.035165*	0.014197	2.476869	0.0133
Q32007	0.054182*	0.021668	2.500545	0.0124
Q42007	0.029164*	0.015815	1.844017	0.0652
Q12008	0.015011*	0.016035	0.936125	0.3493
Q22008	−0.03095*	0.016649	−1.858948	0.0631
Q32008	−0.070712*	0.015362	−4.603062	0
Q42008	−0.096645*	0.016863	−5.73115	0
Q12009	−0.074404*	0.013622	−5.462044	0
Q22009	−0.032798*	0.01684	−1.947659	0.0515
Q32009	−0.026051*	0.016097	−1.618415	0.1056
Q42009	−0.029495*	0.015454	−1.90851	0.0564
Q12010	−0.006611*	0.0147	−0.449768	0.6529
Q22010	−0.04788*	0.014912	−3.210849	0.0013
Q32010	−0.053414*	0.017463	−3.058715	0.0022
Q42010	−0.079494*	0.024203	−3.284415	0.001
Q12011	−0.10889*	0.036143	−3.012767	0.0026
Q22011	−0.130871*	0.033555	−3.90013	0.0001
Q32011	−0.144664*	0.030307	−4.77332	0
Q42011	−0.136139*	0.030441	−4.472183	0
Q12012	−0.121966	0.030967	−3.938572	0.0001
Q22012	−0.125525*	0.032821	−3.824523	0.0001
Q32012	−0.115021*	0.037642	−3.055651	0.0023
Q42012	−0.245882*	0.04664	−5.271872	0
_1920_1929	0.024115*	0.01007	2.39459	0.0167
_1930_1939	0.019662	0.011406	1.72383	0.0848
_1940_1949	−0.028977*	0.012182	−2.378698	0.0174
_1950_1959	−0.014258	0.012134	−1.175021	0.24
_1960_1969	0.002346	0.012961	0.181031	0.8564
_1970_1979	0.013371	0.015578	0.858351	0.3907
_1980_1989	0.037911*	0.017902	2.117706	0.0343
_1990_1999	0.018703	0.016966	1.102359	0.2704
_2000_2009	0.18589*	0.01614	11.51734	0
_2010_2019	0.233522*	0.025923	9.00826	0
EQ1NO_RISK	0.068126	0.035933	1.895941	0.058
EQ1LOW_RISK	0.096681	0.049949	1.935609	0.053
EQ1MEDIUM	0.048775*	0.023272	2.095915	0.0361
EQ2NO_RISK	0.140718*	0.033684	4.177648	0
EQ2LOW_RISK	0.171967*	0.036412	4.72277	0
EQ2MEDIUM_RISK	0.149415*	0.029795	5.014772	0
SUPERIOR_CONDITION	0.100234*	0.024969	4.014303	0.0001
AVERAGE_TO_GOOD_CONDITION	0.030322	0.01821	1.665187	0.0959
BRICK	−0.034934*	0.009671	−3.612197	0.0003
CONCRETE	−0.006779	0.010675	−0.634964	0.5255
FIBROLITE	−0.057888*	0.017468	−3.313897	0.0009
IRON	−0.008166	0.0221	−0.369498	0.7118
MALTHOID	−0.046371*	0.01933	−2.398942	0.0165
PLASTIC	0.047134	0.060118v	0.784034	0.4331
ROUGHCAST	−0.025999*	0.007983	−3.256857	0.0011
STONE	−0.024938	0.025356	−0.983507	0.3254
TILES	−0.008461	0.102727	−0.082366	0.9344

(*Continued*)

Table 4. (*Continued*)

Dependent Variable: LOG_PRICE				
MIXTURE	−0.021551	0.012641	−1.704855	0.0883
LDISTANCE_TO_CBD (LOG)	0.001724	0.001697	1.015686	0.3098
PUBLIC HOUSING (LOG)	−0.014475*	0.002686	−5.388445	0
R^2	0.770565	Mean dependent var		12.74646
Adjusted R^2	0.766172	S.D. dependent var		0.36124
S.E. of regression	0.174681	Akaike info criterion		−0.63291
Sum squared resid	146.6163	Schwarz criterion		−0.50956
Log likelihood	1643	Hannan-Quinn criter.		−0.58963
F-statistic	175.4105	Durbin-Watson stat		1.939921
Prob(F-statistic)	0			

*Denotes 95% level of significance.

about red zone compensation, the remapping of liquefaction zones and more intense media coverage did not occur until after earthquake 2. In addition, significantly more liquefaction damage during earthquake 2 had very real consequences for inhabitants of parts of eastern Christchurch, central Christchurch and Kaiapoi.

EQ2 NO RISK, EQ2 LOW RISK and EQ2 MEDIUM RISK are significant and reveal premiums after the event of 15.1, 18.8 and 16.1%, respectively, compared to the reference EQ2 HIGH RISK dummy variable. This is in stark contrast to the control variables and shows that homeowners' perception of risk became more acute after earthquake 2.

Although intuition would suggest that risk premiums should be linear the fact that the premium for EQ2 LOW RISK is higher than EQ2 NO RISK may simply reflect a preference for location as most low risk zoned land is closer to the city and no risk land is located on the periphery of the Christchurch urban area as well as township areas of Selwyn and Waimakiriri districts. The second earthquake was far more devastating for Christchurch than the first earthquake and the level of liquefaction was immense particularly within The CBD and eastern suburbs. This had very real ramifications for residents who were faced with a huge cleanup, damage to their homes and significant infrastructure damage to roads and sewer networks.

For the amenity variables, the coefficients are also highly significant for land area and floor area which is expected. The coefficients indicate a 1% increase in land area is associated with a 0.15% increase in price and a 1% increase in floor area is associated with a 0.54% increase in price. Houses built from 2000 to 2010 and 2010 onwards command a much higher premium than older homes built before 1920 (20.43% and 26.3% respectively). This result may reflect a preference for newer housing and a general trend towards building larger homes over time. Houses built from 1920 to 1929 and 1980 to 1989 also command a small premium compared to pre 1920s houses and 1940–1949 era houses trade at a discount compared to pre 1920s houses. BRICK, FIBROLITE and ROUGH CAST materials command less of a price than cladding of WOOD/WEATHERBOARD which is the omitted reference variable. The finding that timber-clad houses and 1920–1929 built houses command a premium may reflect a character preference as well as a preference for established areas close to the CBD that typically contain older character homes. Just why 1980–1989 command a small premium is unknown. Again, this may simply reflect location preference for suburbs that were developed in that period. As expected SUPERIOR CONDITION rated houses command a premium over the omitted category of POOR CONDITION, but the coefficient for AVERAGE CONDITION rated houses is insignificant.

The percentage of PUBLIC HOUSING within a statistical meshblock has a significant negative impact on price. A 1% rise in the amount of PUBLIC HOUSING is associated with a .014% discount in PRICE. The DISTANCE TO CBD is not a significant factor in determining PRICE. This is an unusual finding. A simple regression of distance on price confirms there is no evidence of a distance-price gradient. Some higher priced suburbs are located a reasonable distance from the CBD such as the Port Hills suburbs whilst lower priced areas can be found close by the city in eastern suburbs. This may explain this finding.

The time trend quarterly dummy coefficients from the full regression output are plotted in Figure 2. These coefficients represent an index of prices after controlling for variances in property amenity items including floor area and land area, age of house, locality, land hazard zones, condition, and materials. It can be considered superior to commonly available median house price statistics calculated from periodic sales data.

Quarter three in 2007 represented peak prices that were 5.6% higher than first quarter 2007. From quarter three 2007 prices then started falling until quarter four 2008 when they were 9.28% less than quarter one 2007. Most of that fall was recovered until quarter one 2010, but then prices fell again until the third quarter of 2011 were a recovery ensued until the third quarter 2012. The first earthquake occurred in the third quarter of 2010 and it is difficult to argue that it had any effect on already declining prices. The second earthquake occurred in the third quarter of 2011 and appears to have had some effect compared to the first earthquake. A recovery of prices followed the second earthquake which may simply reflect the premium paid as relocating consumers' scrambled for housing from a supply pool reduced by some uninhabitable houses, broken infrastructure making some suburbs undesirable and the red zoning of approximately 6000 houses. This supply constraint combined with an upsurge of demand to live in safer land hazard zones has led to price appreciation generally.

Conclusion

This paper's aim was to answer the following research questions:

(1) Before the earthquakes did homeowners' perceive the risks so that high risk properties sold at a discount as compared to low or no risk properties all else equal?
(2) After the earthquake, did homeowners' show more awareness of risk such that risk related house price differentials widened?

With the exception of the LOW RISK control variable no significant price differentiating is detected in the coefficients for land risk control variables. However, the negative sign of the coefficient is counter-intuitive. Therefore, on balance, the notion that consumers' accounted for land hazard risk prior to the earthquake can be rejected.

In contrast, all coefficients for the three land hazard risk treatment variables are significant after the February 2011 earthquake. Based on the output in Table A4 of the appendix significant price premiums of 15.1, 18.8 and 16.1% are detected across EQ2 NO RISK, EQ2 LOW RISK and EQ2 MEDIUM RISK land hazard categories, respectively, compared to the omitted EQ2 HIGH RISK variable. It is clear that homeowners' showed more awareness of earthquake risk for each land hazard risk zone after the earthquake 2, and this resulted in much wider and significant house price differentials. The non-linear risk premiums are likely to be explained as a consumer preference to be closer to the city than no risk areas.

These findings support those by social researchers on risk perception in the sense that perceptions of risk, particularly perception of risks involving extreme and rare events, is underestimated before the event and overestimated after the event. Information about land hazard risk existed before the earthquake, but was certainly not as easily accessible as it is today. Just how well understood liquefaction risk was by consumers' before the earthquakes remains uncertain. Furthermore, since the liquefaction process requires an earthquake as a catalyst, which are largely unpredictable events in themselves, consumers' may have simply chosen to ignore the risk. Christchurch is also a market where the local history of damaging earthquakes was limited. The fault rupture was also a blind fault with a very low return period, but within close proximity of the city.

It is clear that people's perception of earthquake and liquefaction risk has become more acute after experiencing a real event based on these findings. This is evidenced by price premiums for safer areas following the 22 February 2011 earthquake, but does this also extend to trading off, or giving up, other housing attributes as well? This is an area for further research. Further research is also required to examine the larger sales sample in which the land zone category has changed after the earthquakes. Different methodologies could also be applied to this study such as propensity score matching or repeat sales methods.

Despite the solid results, the R-squared suggests 23% of the variation in prices is unexplained by the model. Although the models fit is reasonably good further research is required to find out why the hedonic model cannot account for all the variation in house prices. This could be explained by surveying a sample of the population to reveal the other influences accounting for consumers' decision-making processes. Social research suggests there will be groups of people that have a higher risk threshold than others, some that accept risk due to cultural, religious beliefs, attachment to a local community, location to one's job or a combination of these reasons. In addition, there may be other risk adverse groups that cannot move due to budget constraints. Understanding the local residents' decision-making may allow authorities to target information about risk to its residents and potentially apply the knowledge learned to other cities with similar risk attributes.

This study's findings have important implications for governments and authorities responsible for the identification and communication of information about all natural hazard risk such as earthquakes, flooding and bushfires. Authorities must also be resourced to identify and classify the risk as this information forms a significant part of the information set used by prospective homeowners, investors, businesses, the insurance sector and lending institutions to inform their decision-making.

Note

1. Budget Policy Statement 2014, New Zealand Treasury.

Disclosure statement

No potential conflict of interest was reported by the author.

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Appendix

Table A1. Pre and post-earthquake land hazard zone nomenclature, definitions and common risk category match.

Pre-earthquake(s) Nomenclature	Definition	Post-earthquake(s) nomenclature	Definition	Determined common risk match
Area not susceptible to liquefaction	No ground damage expected	No risk (rural unmapped)	Not mapped	No risk
L-Bdy	Potential for low subsidence (<100 mm)	Technical Category 1 (TC1)	Future land damage from liquefaction is unlikely, and ground settlements are expected to be within normally accepted tolerances. Standard foundations (NZ 3804) are acceptable subject to shallow geotechnical investigation	Low Risk
L-Uncertain	Insufficient information available for liquefaction prediction. A potential for low subsidence (100–300 mm)	Technical Category 1 (TC1)	As above	Low Risk
M-bdy	Potential for moderate subsidence (<300 mm)	TC2	Minor to moderate land damage from liquefaction is possible in future large earthquakes. Lightweight construction or enhanced foundations are likely to be required such as enhanced concrete raft foundations (i.e. stiffer floor slabs that tie the structure together)	Medium Risk
H-bdy	Potential for significant subsidence (>300 mm)	TC3	Moderate to significant land damage from liquefaction is possible in future large earthquakes. Foundation solutions should be based on site-specific geotechnical investigation and specific engineering foundation design.	High risk
H-Uncertain	Insufficient information available for liquefaction prediction. A potential for significant (> 300 mm) and possible lateral spreading may be expected	TC3	As above	High risk
Port Hills bdy	Port Hills- very low likelihood of liquefaction (area not studied)	Port hills/Banks Peninsula	Port Hills – red zoning relates to rock fall risk which is outside of study	Port Hills zone

Table A2. Descriptive statistics for indicator variables

	Count		Mean	Median	Maximum	Minimum	Std. Dev.
Indicator variables	Number	Frequency (%)	NZ$	NZ$	NZ$	NZ$	NZ$
Q12007	320	6.53	353357	315000	1020000	154000	145344
Q22007	336	6.86	366593	323250	975000	160000	143807
Q32007	140	2.86	380589	327000	1100000	210000	154651
Q42007	309	6.30	382658	330000	1061550	150000	165108
Q12008	252	5.14	374393	327500	1000000	169000	146774
Q22008	213	4.35	356380	305000	1100000	167000	153089
Q32008	209	4.26	361265	311000	925000	160000	144511
Q42008	198	4.04	345799	284000	895000	158000	157477
Q12009	264	5.39	337680	300000	1000000	149333	139973
Q22009	271	5.53	359456	315000	940000	156000	150638
Q32009	289	5.90	367194	327000	1102500	170000	159013
Q42009	313	6.39	371007	328000	1030000	150000	147868
Q12010	238	4.86	371253	330000	992500	160000	142600
Q22010	206	4.20	346484	303250	830000	165000	133054
Q32010	173	3.53	360103	333500	1072806	155000	143800
Q42010	146	2.98	369543	336500	1110000	152000	155273
Q12011	86	1.75	364212	330350	940000	155000	146670
Q22011	98	2.00	399563	347000	1050000	170000	166762
Q32011	158	3.22	386146	366000	900000	152000	131534
Q42011	175	3.57	387248	355000	1030000	162000	155604
Q12012	177	3.61	389091	335000	1020000	158000	163845
Q22012	185	3.77	393350	342000	1020000	151000	175192
Q32012	142	2.90	387505	341775	1000000	150000	163174
Q42012	3	0.06	388333	390000	520000	255000	132508
NO RISK CONTROL	655	13.36	363555	325000	1110000	152000	152953
LOW RISK CONTROL	113	2.31	446618	465000	700000	235000	102605
MEDIUM RISK CONTROL	2922	59.62	377864	325250	1102500	149333	164304
HIGH RISK CONTROL	1211	24.71	339525	315000	895000	150000	112554
EQ1 NO RISK TREATMENT	33	0.67	422641	359000	1110000	152000	215482
EQ1 LOW RISK TREATMENT	6	0.12	412942	343275	652500	309000	138841
EQ1 MEDIUM RISK TREATMENT	152	3.10	365224	318000	915000	181850	151776
EQ1 HIGH RISK TREATMENT	53	1.08	344527	355000	549000	175000	99385
EQ2 NO RISK TREATMENT	146	2.98	400458	356500	1020000	172500	157099
EQ2 LOW RISK TREATMENT	36	0.73	470156	473500	621000	285000	98324
EQ2 MEDIUM RISK TREATMENT	655	13.36	396281	345000	1050000	151000	166741
EQ2 HIGH RISK TREATMENT	124	2.53	318460	315500	741000	150000	111717
BELOW AVERAGE CONDITION	183	3.73	242646	225000	749000	149333	74422
AVERAGE TO GOOD CONDITION	4506	91.94	361946	325000	1110000	150000	138918
SUPERIOR CONDITION	211	4.31	606506	570000	1102500	190000	213897
BRICK	1049	21.40	405526	385000	1072806	158000	138430
CONCRETE	642	13.10	325687	300000	1110000	152000	119769
FIBROLITE	122	2.49	312407	268500	950000	155000	150610
IRON	1	0.02	257000	257000	257000	257000	NA
MALTHOID	1	0.02	392000	392000	392000	392000	NA
PLASTIC	20	0.41	404175	317750	865000	250000	206906
ROUGHCAST	857	17.49	379066	324000	1100000	151000	172447
STONE	36	0.73	545444	443000	1000000	236000	231691
TILES	3	0.06	525000	350000	895000	330000	320585
WOOD	1889	38.54	350234	310000	1102500	149333	143466
MIXTURE	247	5.04	417422	375000	1100000	167000	169079
PRE 1920	542	11.06	335763	300000	1020000	149333	140652
1920–1929	635	12.96	359306	310000	1075000	151000	159748
1930–1939	373	7.61	349177	319000	1000000	150000	128399
1940–1949	468	9.55	330204	295000	1102500	152000	128890
1950–1959	601	12.26	309397	290000	915000	150000	102915
1960–1969	441	9.00	311770	295000	950000	152000	95665
1970–1979	242	4.94	328167	300000	905000	178000	115836
1980–1989	141	2.88	383083	360000	988000	155000	138336
1990–1999	252	5.14	425380	410000	1000000	157500	139188
2000–2009	725	14.79	506832	482500	1110000	160000	159945
2010–2019	83	1.69	478351	452000	1072806	160000	177830

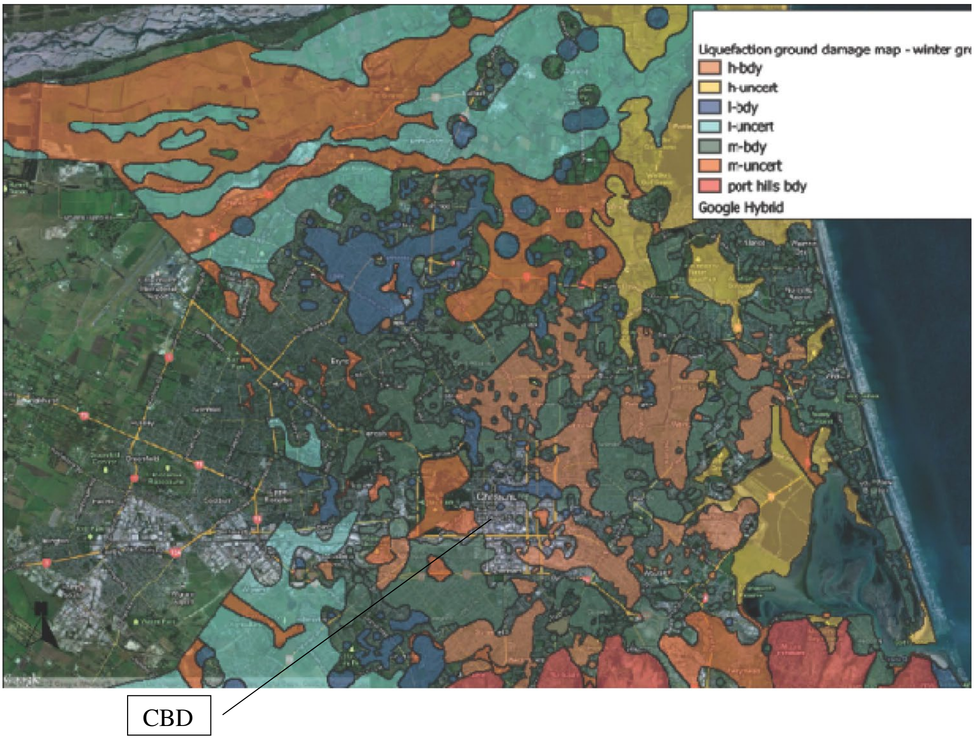

Figure A1. Pre earthquake land hazard zones.

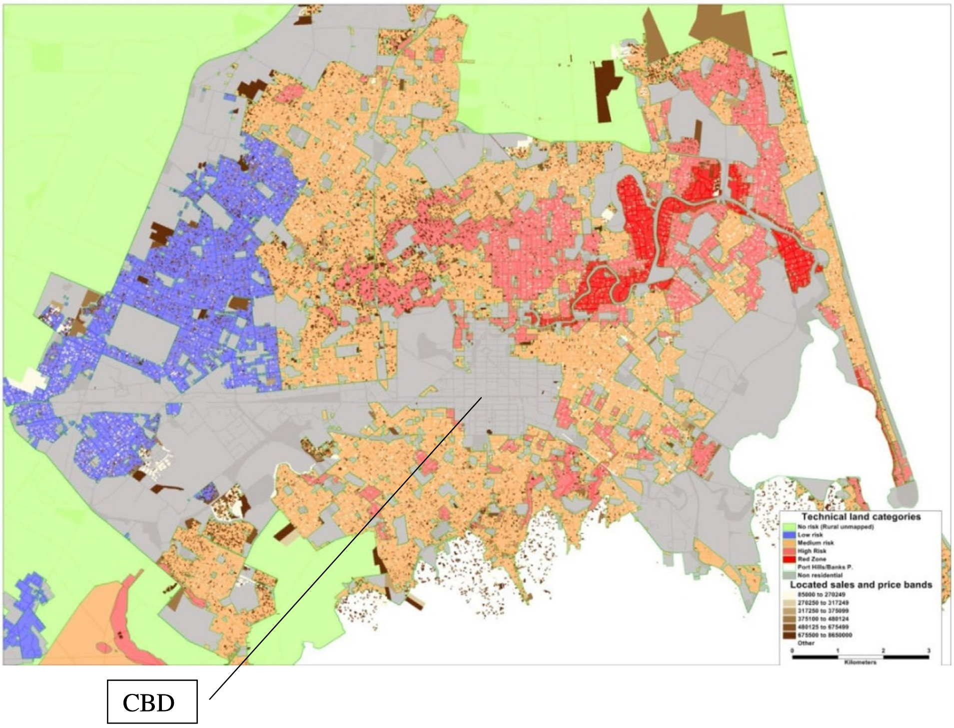

Figure A2. Post-earthquake land hazard zones and located sales.

Table A3. Descriptive statistic for location variables.

Indicator variables	Locality	Count		Mean	Median	Maximum	Minimum	Std. Dev.
		Number	Frequency (%)	NZ$	NZ$	NZ$	NZ$	NZ$
SUBURB 1	Aranui; Wainoni; Burwood; Avondal	258	5.3	268440	261500	545000	152000	65385
SUBURB 2	Avonhead;Russley	18	0.4	491478	450000	749000	319600	125508
SUBURB 3	Beck;Addin;Syden;Waltham;Opawa	312	6.4	322038	295000	950000	149333	111434
SUBURB 4	Bryndwr; Wairakei	56	1.1	403691	326250	917500	192000	190891
SUBURB 5	Burwood; Parklands	340	6.9	413271	422500	1020000	165000	107458
SUBURB 6	Casebrook; Bishopdale	7	0.1	364000	300000	731500	252500	170163
SUBURB 7	Cashmere; Westmorland	18	0.4	510278	445000	810000	325000	171537
SUBURB 8	Central city	36	0.7	488653	410000	925000	150000	200418
SUBURB 9	Ellesmere	11	0.2	421123	421000	560000	287500	70876
SUBURB 10	Fendalton	124	2.5	702216	677625	1102500	338000	178687
SUBURB 11	Halswell	92	1.9	504806	494500	825000	242600	82803
SUBURB 12	Hoon hay	25	0.5	344400	324000	613000	247000	80630
SUBURB 13	Hornby; Hei Hei; Islington	36	0.7	433575	425500	865000	209000	128758
SUBURB 14	Ilam; Burnside	21	0.4	472436	430000	885000	325000	133091
SUBURB 15	Kaiapoi	1	0.0	255000	255000	255000	255000	NA
SUBURB 16	Linwood; Charleston	380	7.8	290467	269750	899000	150000	100104
SUBURB 17	Loburn	3	0.1	319167	335000	350000	272500	41105
SUBURB 18	Merivale	169	3.4	560280	510000	1050000	270000	195334
SUBURB 19	Mt pleasant to Taylors mistake	78	1.6	477163	432500	1110000	215000	168876
SUBURB 20	New Brighton; Nth Sth and Centr	343	7.0	308256	290000	755000	150000	98981
SUBURB 21	Oxford	1	0.0	250000	250000	250000	250000	NA
SUBURB 22	Papanui; Elmwood	213	4.3	498950	460000	1030000	176127	174360
SUBURB 23	Per/Rural; Belfast; Brookl; Templ	327	6.7	489338	486500	1100000	165000	169228
SUBURB 24	Rangiora	25	0.5	326880	295000	530000	210000	76586
SUBURB 25	Rangiora rural; Eyre	1	0.0	220000	220000	220000	220000	NA
SUBURB 26	Redwood; Northcote	77	1.6	357994	345000	560000	176500	68401
SUBURB 27	Riccarton; Middleton	90	1.8	397138	360000	905000	187500	131569
SUBURB 28	Shirley; Dallington; Avons; Richm	283	5.8	291604	277000	1072806	170000	89418
SUBURB 29	Somerfield; Spreydon	629	12.8	310430	300000	680000	151000	74163
SUBURB 30	St albans; Mairehau	584	11.9	344483	329500	895000	162000	91993
SUBURB 31	St Martins; Aynsley; Hunts, Hills	75	1.5	323793	299000	576000	195000	85466
SUBURB 32	Templeton	3	0.1	504833	515000	572500	427000	73281
SUBURB 33	Townships	3	0.1	318333	312500	360000	282500	39078
SUBURB 34	Upper Riccarton,Sockburn	15	0.3	358707	351000	546000	240000	80809
SUBURB 35	Woolston; Bexley; Ferrym; Bromley	247	5.0	324909	294000	875000	170000	113871
		4901						

Table A4. Equation 3. Full OLS regression output following Newey and West procedure.

Dependent Variable: LOG_PRICE

Method: Least Squares

Included observations: 4898

HAC standard errors & covariance (Bartlett kernel, Newey-West fixed bandwidth = 10.0000)

Variable	Coefficient	Std. Error	*t*-Statistic	Prob.
Constant	9.003708	0.069017	130.4561	0
LAND AREA (LOG)	0.146032	0.011739	12.43994	0
FLOOR AREA (LOG)	0.536583	0.01458	36.80329	0
NO_RISK	−0.017728	0.011222	−1.579801	0.1142
LOW_RISK	−0.054476	0.020695	−2.632365	0.0085
MEDIUM_RISK	−0.000719	0.008175	−0.088007	0.9299
Q22007	0.035165	0.014197	2.476869	0.0133
Q32007	0.054182	0.021668	2.500545	0.0124
Q42007	0.029164	0.015815	1.844017	0.0652
Q12008	0.015011	0.016035	0.936125	0.3493
Q22008	−0.03095	0.016649	−1.858948	0.0631
Q32008	−0.070712	0.015362	−4.603062	0
Q42008	−0.096645	0.016863	−5.73115	0
Q12009	−0.074404	0.013622	−5.462044	0
Q22009	−0.032798	0.01684	−1.947659	0.0515
Q32009	−0.026051	0.016097	−1.618415	0.1056
Q42009	−0.029495	0.015454	−1.90851	0.0564
Q12010	−0.006611	0.0147	−0.449768	0.6529
Q22010	−0.04788	0.014912	−3.210849	0.0013
Q32010	−0.053414	0.017463	−3.058715	0.0022
Q42010	−0.079494	0.024203	−3.284415	0.001
Q12011	−0.10889	0.036143	−3.012767	0.0026
Q22011	−0.130871	0.033555	−3.90013	0.0001
Q32011	−0.144664	0.030307	−4.77332	0
Q42011	−0.136139	0.030441	−4.472183	0
Q12012	−0.121966	0.030967	−3.938572	0.0001
Q22012	−0.125525	0.032821	−3.824523	0.0001
Q32012	−0.115021	0.037642	−3.055651	0.0023
Q42012	−0.245882	0.04664	−5.271872	0
_1920_1929	0.024115	0.01007	2.39459	0.0167
_1930_1939	0.019662	0.011406	1.72383	0.0848
_1940_1949	−0.028977	0.012182	−2.378698	0.0174
_1950_1959	−0.014258	0.012134	−1.175021	0.24
_1960_1969	0.002346	0.012961	0.181031	0.8564
_1970_1979	0.013371	0.015578	0.858351	0.3907
_1980_1989	0.037911	0.017902	2.117706	0.0343
_1990_1999	0.018703	0.016966	1.102359	0.2704
_2000_2009	0.18589	0.01614	11.51734	0
_2010_2019	0.233522	0.025923	9.00826	0
EQ1NO_RISK	0.068126	0.035933	1.895941	0.058
EQ1LOW_RISK	0.096681	0.049949	1.935609	0.053
EQ1MEDIUM	0.048775	0.023272	2.095915	0.0361
EQ2NO_RISK	0.140718	0.033684	4.177648	0
EQ2LOW_RISK	0.171967	0.036412	4.72277	0
EQ2MEDIUM_RISK	0.149415	0.029795	5.014772	0
SUPERIOR_CONDITION	0.100234	0.024969	4.014303	0.0001
AVERAGE_TO_GOOD_CONDITION	0.030322	0.01821	1.665187	0.0959
BRICK	−0.034934	0.009671	−3.612197	0.0003
CONCRETE	−0.006779	0.010675	−0.634964	0.5255
FIBROLITE	−0.057888	0.017468	−3.313897	0.0009
IRON	−0.008166	0.0221	−0.369498	0.7118
MALTHOID	−0.046371	0.01933	−2.398942	0.0165
PLASTIC	0.047134	0.060118	0.784034	0.4331
ROUGHCAST	−0.025999	0.007983	−3.256857	0.0011
STONE	−0.024938	0.025356	−0.983507	0.3254
TILES	−0.008461	0.102727	−0.082366	0.9344

(*Continued*)

Table A4. (*Continued*)

MIXTURE	−0.021551	0.012641	−1.704855	0.0883
LDISTANCE_TO_CBD (LOG)	0.001724	0.001697	1.015686	0.3098
PUBLIC HOUSING (LOG)	−0.014475	0.002686	−5.388445	0
SUBURB 2	0.303797	0.027783	10.93461	0
SUBURB 3	0.151292	0.020857	7.253911	0
SUBURB 4	0.211052	0.024407	8.647264	0
SUBURB 5	0.098946	0.014725	6.719468	0
SUBURB 6	0.116373	0.040695	2.859628	0.0043
SUBURB 7	0.34686	0.033829	10.25326	0
SUBURB 8	0.43216	0.049262	8.772742	0
SUBURB 9	−0.061397	0.043979	−1.396054	0.1628
SUBURB 10	0.63193	0.022286	28.35596	0
SUBURB 11	0.131747	0.024564	5.363503	0
SUBURB 12	0.174615	0.023961	7.287318	0
SUBURB 13	0.157777	0.044198	3.569804	0.0004
SUBURB 14	0.30514	0.036161	8.438326	0
SUBURB 15	0.036705	0.019434	1.888713	0.059
SUBURB 16	0.010462	0.018743	0.558154	0.5768
SUBURB 17	−0.048232	0.030523	−1.580203	0.1141
SUBURB 20	0.516629	0.024013	21.51454	0
SUBURB 21	0.494854	0.02868	17.25434	0
SUBURB 22	0.136906	0.017784	7.698275	0
SUBURB 23	−0.243635	0.026426	−9.219681	0
SUBURB 24	0.354566	0.022591	15.6948	0
SUBURB 25	0.112329	0.018931	5.933634	0
SUBURB 26	0.003919	0.025766	0.152103	0.8791
SUBURB 27	−0.034835	0.026625	−1.308362	0.1908
SUBURB 28	0.113439	0.019768	5.738451	0
SUBURB 29	0.261864	0.026559	9.859644	0
SUBURB 30	0.060341	0.015531	3.885283	0.0001
SUBURB 31	0.127327	0.017094	7.448664	0
SUBURB 32	0.188667	0.015282	12.34564	0
SUBURB 33	0.149605	0.023765	6.295095	0
SUBURB 34	0.044283	0.034097	1.298707	0.1941
SUBURB 35	0.111215	0.075455	1.473923	0.1406
SUBURB 36	0.148909	0.043087	3.456	0.0006
SUBURB 37	−0.017609	0.016236	−1.084583	0.2782
R^2	0.770565	Mean dependent var		12.74646
Adjusted R^2	0.766172	S.D. dependent var		0.36124
S.E. of regression	0.174681	Akaike info criterion		−0.63291
Sum squared resid	146.6163	Schwarz criterion		−0.50956
Log likelihood	1643	Hannan-Quinn criter.		−0.58963
F-statistic	175.4105	Durbin-Watson stat		1.939921
Prob(*F*-statistic)	0			