That Sinking Feeling: The Changing Price of Disaster Risk Following an Earthquake

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Abstract

We treat the Canterbury (Christchurch) earthquake sequence as a potential source of new risk information to home buyers in New Zealand. We compare pre- and post-earthquake sales of properties in two other urban areas of the country (one with high and one with low seismicity) to estimate how the pricing of earthquake-related risks changed following the Canterbury earthquakes. Specifically, we test for changes in risk premia associated with soil liquefaction potential, previously a largely ignored hazard, and changes in premia for house construction types (such as brick) that previously were well-known to be less safe in an earthquake. By exploiting two types of risk (one previously ignored and one well-recognised by households) across two areas with differing seismic risks, pre- and post-earthquake, we use a difference-in-difference-in-difference approach to test hypotheses about how people respond to a new clearly defined risk that is important only in certain circumstances. We find no evidence that the price of known construction risk changed in either seismic area and no evidence of a change in the price of liquefaction risk in the low seismic area following the Canterbury earthquakes. However, we do find strong evidence that a liquefaction risk discount emerged in the high seismic area immediately after the Canterbury earthquakes. These findings are all in accord with rational responses to risk following the earthquakes. However, the liquefaction risk discount in the high seismic area dissipated after two years and had disappeared entirely within three years of the earthquakes. This finding is similar to those identified in a limited number of previous empirical studies on responses to natural hazard events. While we cannot rule out entirely that this time-varying risk premium is a rational response to risk (e.g. because of changing expectations around insurable versus non-insurable risks), we find it more plausible that these changing risk discounts reflect behavioural responses to risk as indicated in the cognitive dissonance literature.

JEL codes

Q54, R21, R30

Keywords

Property values, earthquake risk, cognitive dissonance, hedonic model, repeat sales model

Contents

1. Introduction

Standard economic models assume that people rationally assess risk and reflect this assessment in their actions and pricing decisions. By contrast, some behavioural economics approaches, including the cognitive dissonance approach highlighted by Akerlof and Dickens (1982), suggest that in certain circumstances people downplay personal risks that a disinterested rational observer would consider to be material. In practice, it is difficult empirically to assess whether such a cognitive dissonance effect exists as exogenous changes in risk factors that were previously unknown and that then become known are rare. Furthermore, even in such circumstances, the emerging risk may be correlated with other factors that emerge at the same time making isolation of the effect of the new risk problematic.

We utilise a natural experiment, the 2010-11 Christchurch (Canterbury Region) earthquake sequence, as a source of new risk information to households in New Zealand. The earthquakes, which caused 185 fatalities, resulted in physical damage that corresponded approximately to one-fifth of New Zealand's annual GDP. Much of the damage arose as a result of the physical phenomenon of soil liquefaction that caused exaggerated shaking of buildings located on liquefaction-prone land. We hypothesise that the earthquakes affected risk perceptions of liquefaction, a hazard that we show was not previously well understood by the public. We hypothesise that a rational response to the newly understood risk associated with location in a liquefaction-prone zone that is also subject to high seismicity (earthquake) risk is to discount the price of existing houses located in such a zone relative to houses in a non-liquefaction zone in the same seismic area. Houses in these locations should also be discounted relative to houses in a liquefaction-prone zone in an area of low seismicity. We hypothesise further that discounts associated with well-known risks, such as those associated with brick construction (relative to weatherboard construction, which is considered to be the most earthquake-resistant building material commonly used for housing in New Zealand) will not have changed in areas with either high or low seismicity following the earthquakes.

For the newly highlighted risk (liquefaction), the question posed by the cognitive dissonance literature (Akerlof and Dickens, 1982) is whether the risk is rationally reflected in house prices in the high seismic area, both initially and longer term. When the risk has high salience (shortly after the earthquakes) we hypothesise that it will be reflected as a discount since its prominence in the media makes it difficult for a prospective purchaser to ignore. However, as its salience diminishes over time, the marginal prospective house purchaser may override the risk if other features of a house make it an otherwise preferred purchase. This behaviour would be consistent with a key feature of the cognitive dissonance approach: that (at least some) people have preferences not only over states of the world but also over their beliefs about the states of the world.[1] The fact that liquefaction-potential is not directly observed (being below ground) may exacerbate its declining salience over time relative to observable risks (such as construction materials) and relative to observable features of a house that appeal to the marginal purchaser. If this were the case, we would expect to find an initial discount associated with liquefaction in a high seismic area but that this discount will then dissipate over time.[2]

We test this set of hypotheses using a dataset of residential property market transactions in two cities that are situated outside of the Canterbury Region, Dunedin City and Hutt City. We compare pre- and post-earthquake sale prices of properties located in a liquefaction potential zone relative to those located outside that zone but within the same urban area. Compared with other areas of New Zealand, Dunedin City has low levels of seismic risk. On the other hand, Hutt City (within the Wellington Region[3]) sits on one of the country's most active geological faults, and other significant active faults run nearby. The Wellington Region has been affected by several damaging earthquakes since European colonisation. We also compare pre- and post-earthquake sale prices of properties that are made of different construction materials located within the same urban area. Thus our research design utilises a difference-in-difference-in-difference approach: we compare discounts associated with known versus hitherto ignored risks, across areas of high and low seismicity, pre- and post-earthquake. Furthermore, we test for a time-varying risk discount post-earthquake.

Our results show no evidence that the risk associated with liquefaction potential was priced into residential properties in either city prior to the 2010 Canterbury earthquake. Following the earthquake, we find no significant change in the risk premium attached to non-weatherboard houses in either Hutt City or Dunedin City, nor do we find any evidence of a change in the risk premium associated with liquefaction-prone land in the area of low seismic risk (Dunedin). By contrast, we find a significant increase in the discount associated with liquefaction-prone land in (high seismicity) Hutt City. However, this risk premium (of around 2%) lasts for only about two

[1] For example, not only do I prefer a prospective purchase area to be safe, but I also prefer to believe that the area in which I wish to purchase is safe, given that other attributes of the prospective purchase make that house a preferred purchase.

[2] Akerlof and Dickens suggest that cognitive dissonance may explain why people in areas with high risk of flood or earthquake damage fail to purchase actuarially fair insurance. In New Zealand's case, insurance coverage is extremely high. However, even actuarially fair insurance for the property fails to cover extraneous personal costs of earthquake damage, so we extend the Akerlof and Dickens suggestion to cover the discount built into the price of a house that is built on liquefaction-prone land.

[3] Wellington is the capital city of New Zealand.

years and fully dissipates within three years of the earthquakes. Such a short-term impact is consistent with predictions of the cognitive dissonance approach. It is also in accord with a limited number of other studies that characterise processes for updating expectations of, and reactions to, uncertain and infrequently observed events (Gallagher, 2014; Bin and Landry, 2013). However our study is unique in adopting a difference-in-difference-in-difference approach that differentiates both across risk types and by risk potential before and after a natural hazard event.

Prior to testing our hypotheses, section two provides context to our analysis. It briefly reviews the Canterbury earthquakes and their aftermath, summarises relevant risk information available to property purchasers in Dunedin and Hutt City, and synthesises findings from previous studies. Section three provides a discussion of our modelling framework and introduces both hedonic and repeat sales models, while section four describes our data. In section five, we present and discuss estimation results. Section six concludes the paper.

2. Background

A magnitude 7.1 earthquake struck Christchurch and the surrounding region in the early hours of 4 September 2010. Although it caused no fatalities, the event was the most damaging earthquake to hit New Zealand in almost 80 years. Less than six months later, on 22 February 2011, another major shallow earthquake measuring 6.3 on the Richter scale (with an exceptionally high peak ground acceleration) struck the city killing 185 people and injuring thousands.

The earthquakes caused major damage to the economy of the region. The city's central business district remained cordoned off for more than two years. By mid-2013, the Canterbury Earthquake Recovery Authority (CERA) estimated that the earthquakes had severely damaged around 16,000 properties with over 9,000 becoming uninhabitable. Claims to the Earthquake Commission (EQC), New Zealand's government-owned provider of natural disaster insurance to owners of residential properties, indicate that over 90% of residential properties in greater Christchurch sustained some damage (Goodyear, 2014). Thousands of people left due to uninhabitable homes, lack of basic services and the psychological stress of continuing aftershocks. The Treasury (2013) estimates that total investment associated with the rebuild will be around $40 billion.[4]

The earthquakes badly damaged many older brick and mortar buildings. However, most of the damage to residential homes was a result of severe soil liquefaction: the earthquake's shaking

[4] In December 2013, 1 NZ dollar = 0.8228 US dollars. New Zealand's annual GDP in the year to December 2013 was $221 billion, implying that the estimated rebuild cost is equivalent to 18% of annual GDP.

rearranged soil particles causing water-saturated layers of soft sand and silt to lose strength and behave like a liquid (Buchanan and Newcombe, 2010). Liquefaction undermined foundations and destroyed critical infrastructure.

Approximately 20,000 houses were seriously affected by liquefaction with 6,000 damaged beyond repair (Cubrinovski et al., 2012). Some parts of Christchurch, affecting thousands of homes, were categorised as a residential red zone – these areas were damaged to such an extent that they are unlikely to be suitable for continued occupation for a prolonged period of time and may never be rebuilt. Despite the generally high insurance penetration that characterises New Zealand, homeowners in the affected areas indisputably faced significant costs associated with social dislocation as well as sometimes long delays in insurance settlements.

The location of liquefaction-prone land and the risks associated with liquefaction had been well documented by geologists at least since Brown and Weeber (1992), and instances of liquefaction in Christchurch had occurred in three earthquakes occurring between 1869 and 1922 (Brackley, 2012). However, property developers, subsequent property owners, insurers and banks all appeared to ignore or downplay these risks prior to the 2010 earthquake. For instance, a development in Bexley suburb, one of the worst-hit parts of Christchurch, was purchased by private developers in the late 1980s directly from the Christchurch Council for the purpose of building houses. At no stage, including when the land was rezoned for housing in 1992, did the Council or others formally object to the development of houses on the basis of liquefaction potential (Hutching, 2010). There is no evidence that subsequent owners had any difficulty in accessing mortgage finance or house insurance for their property purchases.

Widespread media reporting on the Christchurch events led to a sudden increase in liquefaction hazard awareness in New Zealand – the word quickly became part of the everyday vocabulary after the first earthquake. For instance, in the year prior to the September 2010 earthquake, the word "liquefaction" only appeared once in the *New Zealand Herald*, the country's largest circulation newspaper. In the year following the first earthquake, the word appeared 353 times in that newspaper. The word then appeared with declining frequency over the succeeding three years (90, 52 and 18 times respectively).

Other areas of the country are potentially susceptible to soil liquefaction in a large earthquake.[5] Our primary objective is to test whether the tangible demonstration of the effect of liquefaction provided by the earthquakes resulted in changes to residential property prices in

[5] Liquefaction in the September 2010 and February 2011 earthquakes generally occurred in areas where liquefaction susceptibility had been predicted to be relatively high (Brackley, 2012).

liquefaction-prone areas of Dunedin City and Hutt City. Both cities lie outside of the Canterbury Region and a significant portion of their population lives on reclaimed land or close to estuaries or rivers. These areas are potentially susceptible to liquefaction in a large earthquake. In terms of the strength of ground shaking, minor liquefaction may occur in susceptible ground at Modified Mercalli Intensity 7 (MM7). Shaking of MM9 is expected to produce severe damage in areas where the soil is prone to liquefaction. In Dunedin, the return periods for exceedance of MM7 and MM9 are estimated to be 350 years and 13,000 years, respectively. In Hutt City, the corresponding return periods are just 30 years and 400 years (Cousins, 2012). Thus we treat Dunedin as an area of low seismicity and Hutt City as an area of high seismicity.

Both city councils disclose the risk associated with liquefaction potential in the form of cautionary advice included in Land Information Memoranda (LIM) issued for the affected properties.[6] The information was available to homebuyers even prior to the Canterbury earthquakes.[7] However, following the first earthquake, the Dunedin City Council decided to give greater prominence to the advice on liquefaction; the message was modified in late 2010 to explicitly include the word liquefaction (Garrett, 2013). The advice for affected properties now reads:

> "This area has been identified as lying within a zone susceptible to amplified shaking in an earthquake and potential liquefaction during a severe earthquake event. The Dunedin City Council will require a site specific design for any new building foundation construction in this area."

The change in wording is not indicative of a reassessment of liquefaction risk, and the scientific basis of the advice is the same as previously (Soils and Foundations, 1993). The change was only made to clarify the nature of the information in the context of increased public awareness of liquefaction (Garrett, 2013). Nevertheless, the move was widely contested in Dunedin as many feared that the change in wording alone could be misinterpreted and affect property values or jeopardise owners' ability to acquire insurance cover in the area (Loughrey, 2010).[8]

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[6] A LIM is a comprehensive report issued by the council that has all relevant information known about a property or section. It includes a section on site hazards. It is standard practice for property buyers in New Zealand to obtain a LIM, and it is required by banks if the property has a mortgage.

[7] Anecdotal evidence, however, suggests that before the earthquakes, purchasers (and banks providing mortgage loans) disregarded this information either because they considered the risk of an earthquake to be low or because they were not aware of the specific risks associated with liquefaction (or both).

[8] Insurance premiums in New Zealand were previously not adjusted for liquefaction risk, and conversations with insurance companies confirm that neither the ability to purchase insurance in liquefaction potential zones nor its pricing has been affected since the earthquakes.

In Hutt City, areas prone to liquefaction are further classified into high, moderate and variable (low to high) potential zones. The wording of the advice has been unchanged for several years (pre- and post-earthquake) and reads:

> "The property is in a zone of [no potential (sic) OR variable (low to high) OR moderate OR high] liquefaction potential. See Greater Wellington Regional Council publication WRC/PP-T-93/74 for more information."

In addition to the site-specific information provided to home buyers via LIMs, the Hutt City Council makes maps of the affected areas freely available to the public, so property buyers can readily compare liquefaction potential and other hazards across different areas of the city.

We also examine whether residential property prices were affected by (previously well-recognised) risks associated with the type of house construction. Risk of collapse or severe damage amongst brick and unreinforced masonry buildings in earthquakes had been shown repeatedly in earlier New Zealand earthquakes including the 1848 and 1855 earthquakes that struck Wellington, the 1929 Murchison earthquake, the 1931 Napier earthquake and the 1942 Wairarapa earthquakes (all ranging between 7.2 and 8.2 on the Richter scale). Thornton (2010) reports that following the 1855 earthquake, for the rest of the nineteenth century construction was predominantly in timber (weatherboard). Fires and "sufficient time for the memories of earthquakes to grow dim" led to a resumption of brick construction in the early twentieth century. However the Murchison and Napier earthquakes saw a major decline in brick construction.

Several previous studies have demonstrated that property markets internalise the perceived risk associated with natural hazards. The price of a property within a flood prone area, for example, tends to be lower than the price of an otherwise identical property elsewhere (Bin and Kruse, 2006; Samarasinghe and Sharp, 2010).

Studies have also shown that property buyers' risk perceptions change with the prevalence of hazard events. Experience with flooding raises the perceived risk associated with flood prone areas (Lawrence et al., 2014) and consequently affects property values in these areas (Bin and Polasky, 2004). Likewise, property markets have been shown to be responsive to earthquake risk following large seismic events in both the United States and Japan (Murdoch et al., 1993; Naoi et al., 2009).

Results from recent empirical research suggest that these effects may be only temporary. In examining learning processes about uncertain and infrequently observed events, Gallagher (2014) finds that regional floods in the United States increase the demand for flood insurance. Insurance take-up spikes the year after a flood, but then steadily declines to baseline levels.

Evidence indicates that property prices also bounce back, and any risk discount attributed to the event disappears within a few years (Bin and Landry, 2013). Klimova and Lee (2014) find a similar short-lived risk discount placed on houses located near a murder site in Sydney, but in this instance, a short-lived discount may be more warranted than a permanent discount based on the objective risks pertaining to the event.

In this paper, we use our difference-in-difference-in-difference approach to consider whether the earthquakes that struck Christchurch served as a source of new risk information to property buyers in (low-seismicity) Dunedin City and (high seismicity) Hutt City – urban areas in New Zealand that were not directly affected by the disaster. We test whether the earthquakes changed the risk discount associated with liquefaction, especially in the high seismic area, and whether it affected discounts associated with the construction type of a house. The impact of liquefaction potential on residential property prices has never before been assessed empirically.

3. Modelling Framework

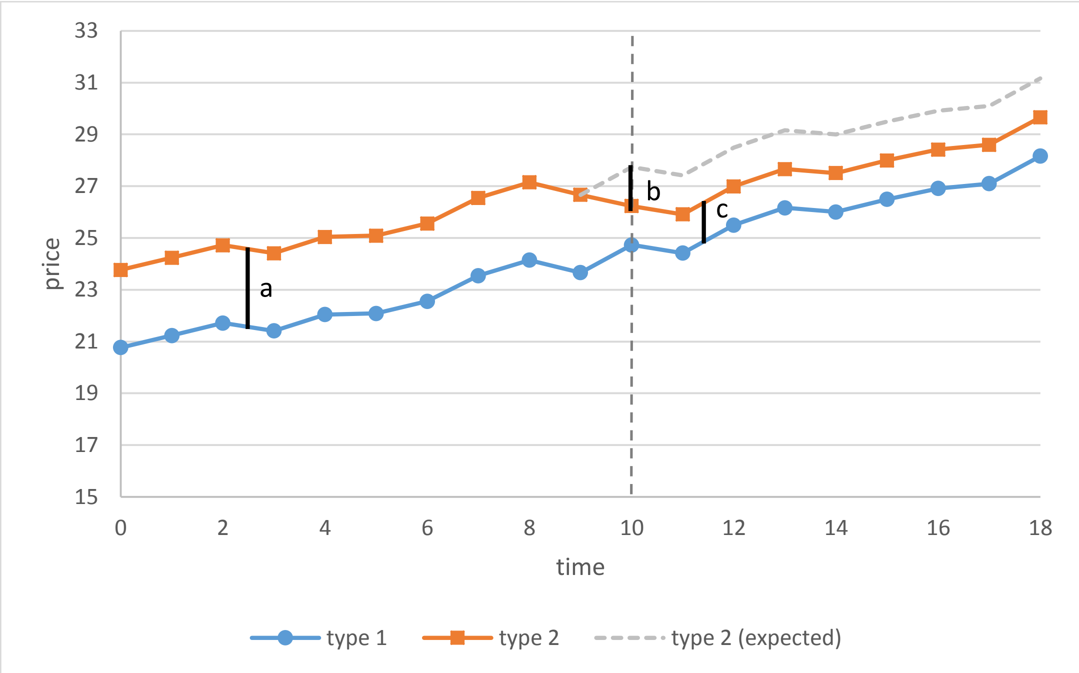
In order to test how liquefaction- and construction-related risk is priced in residential property markets before and after the earthquakes, we must control for a range of other factors that affect local property prices. The impacts that we estimate are relative to a control group: we evaluate price movements in liquefaction-prone areas relative to price movements in nearby non-liquefaction-prone areas, and we evaluate price movements associated with brick (or other) construction types relative to the price movements experienced by homes of weatherboard construction within the same urban area.

We perform our estimates on property market transactions data from two cities (with different levels of seismic risk) using models based on hedonic pricing and repeat sales methods. Traditional applications of the two methods provide different identification strategies and different insights. This is illustrated in figure 3.1. The figure displays hypothetical price series for two types of properties over time (for example, houses of type 2 may be in a liquefaction potential zone, and houses of type 1 outside this zone). In general, both price series move together because they are subject to the same economic shocks. At time 10, an event occurs that causes the value of properties in the group labelled type 2 to fall, while it does not affect other properties.[9] Based on certain assumptions (particularly the absence of systematic unobserved effects), the hedonic model can estimate both pre-event differences between the price levels of the two types of properties due

[9] The illustration shows a fall in the absolute price level of type 2 properties, but this need not be the case: identification only requires a change in relative prices.

to a particular characteristic such as liquefaction (a), and the effect of the event on the price of properties with this characteristic (b). Post-event differences in prices are then straightforward to calculate ($c = a - b$). In the repeat sales model, only relative changes between the two price levels are identified (b). However, the repeat sales model offers much better control for unchanging house characteristics, including all unobserved characteristics, so the estimates from the repeat-sales method are subject to less omitted variable bias than the hedonic estimates (McMillen and McDonald, 2004).

Figure 3.1. Illustration of identification in the two models



3.1. Hedonic Model

The hedonic property value model is among economists' leading tools for evaluating factors that are not explicitly traded in markets but do affect the choice of a home (Lancaster, 1966; Rosen, 1974). The basic premise of the model is that the price of a house can be decomposed into the value of the characteristics and services it provides. The hedonic model is routinely applied to estimate the value of various environmental amenities, local public services or implicit risk premiums associated with human-made and natural hazards (e.g., Bin and Landry, 2013; Samarasinghe and Sharp, 2010).

We specify a log-linear hedonic price equation:[10]

[10] In a log-linear model, the coefficient of a covariate corresponds to the expected proportional change in the dependent variable for a unit increase in the covariate. A log-linear relationship is chosen as property values are

$$\log(P_{it}) = \bar{\alpha} + \mu_t + \beta X_{it} + \gamma Z_{it} + \delta Z_{it} d^{EQ} + \varepsilon_{it}, \quad (1)$$

where the natural logarithm of the sales price of house i at time t (P_{it}) is a function of various structural, location and neighbourhood characteristics (X_{it}) and earthquake-related characteristics (Z_{it}) that categorise the liquefaction potential and construction type of the house.[11] We also interact these variables with a post-earthquake indicator (d^{EQ}) whose value equals one in all time periods following the first earthquake and zero otherwise. Our main interest lies in the estimation of δ: these parameters characterise the impact the earthquakes had on the pricing of earthquake-related risks. The hedonic model also enables us to estimate γ, the pre-event differences in prices associated with these risks.

Equation (1) also includes a constant ($\bar{\alpha}$), time-specific fixed effects (μ_t) to account for quarterly generalised property price changes, and an idiosyncratic error term (ε_{it}). We cluster the errors on houses. This allows errors to be correlated within houses (that is, across multiple observations of the same house), but not across houses. This clustering does not affect the estimated coefficients, but improves inference by yielding robust standard errors.

3.2. Repeat Sales Model

We employ the two-way fixed effects repeat sales estimation method (Gao and Wang, 2007; Grimes and Young, 2010; Grimes and Young, 2013), supplemented by additional terms. Fixed effects models provide a means of controlling for omitted variable bias because in a fixed-effects model, each house serves as its own control. The repeat sales model thus makes better use of multiple observations of a house. The general form of our estimating equation is, as for the hedonic model, log-linear:

$$\log(P_{it}) = \bar{\alpha} + \alpha_i + \mu_t + \beta X_{it} + \gamma Z_{it} + \delta Z_{it} d^{EQ} + \varepsilon_{it}. \quad (2)$$

This equation specifies the natural log of the sales price of house i at time t (P_{it}) as a function of a constant ($\bar{\alpha}$), a house-specific fixed effect (α_i), a time-specific fixed effect (μ_t), any changing house characteristics (X_{it}), any changing earthquake-related variables (Z_{it}), a post-earthquake indicator (d^{EQ}) interacted with Z_{it}, and an idiosyncratic error term (ε_{it}). The interaction of d^{EQ} with Z_{it} introduces an hedonic aspect to our repeat sales approach, allowing the price associated with certain earthquake-related characteristics to vary pre- versus post-earthquake.

expected to move together in proportionate terms over time. The log-linear functional form also corrects for heteroscedasticity between the dependent variable and the residuals (Basu and Thibodeau, 1998).

[11] We include time subscripts on X_{it} and Z_{it} to acknowledge that some house characteristics may change over time. The liquefaction potential classification is constant for each house in our dataset.

Similar to the hedonic model, we use errors clustered on the panel variable (houses) in the repeat sales model, yielding robust standard errors.

The house fixed effects control for all unchanging characteristics of each house. They soak up both observed and unobserved within-house variation, so their inclusion means that the impact of any unchanging characteristic, unless interacted with a time variable, cannot be estimated in this model. The inclusion of βX_{it} and γZ_{it} provides mechanical controls for houses whose attributes change between two sales.[12] The time fixed effects control for overall quarterly house price movements in the full sample of houses within the study area.

Our focus in the repeat sales model is, firstly, on whether houses situated on a property potentially subject to liquefaction changed in price (relative to properties not subject to liquefaction) following the first Canterbury earthquake. Secondly, we focus on whether houses with non-weatherboard construction (brick and 'other') changed in price (relative to weatherboard houses) following the earthquake.

The models described in equations (1) and (2), as well as the illustration in figure 3.1, suppose that the earthquake has a one-off permanent effect on risk premia. However, as noted in section 2, some prior studies find that risk pricing is affected only temporarily by an event. If this were the case, the relevant coefficient will initially be negative following the earthquake, but will eventually revert back towards zero. In our estimation procedure, we initially test for a permanent effect, and then test whether the post-earthquake effect varies with the length of time following the event.

4. Data

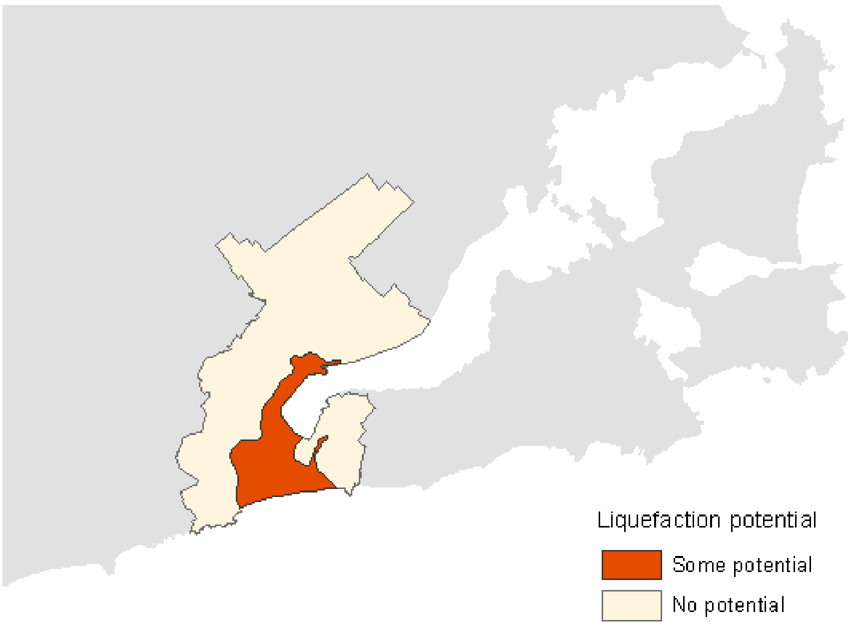
To implement the models, we obtained records of property sales classified by liquefaction potential from PropertyIQ.[13] We describe details of the sampling procedure and provide summary statistics for each study area. All sales in our estimation samples are for single detached residential freehold properties located in areas classified as residential by each council's land zoning code.

[12] An observed change in characteristics indicates that an administrative record has been altered between sales, either to account for an actual change in the house (e.g. addition of a bedroom) or because a record has been updated with new information that may correct earlier data. We repeat our estimates on a conservative sample that excludes houses with changing characteristics as a robustness check.
[13] Property IQ is a partly-owned subsidiary company of Quotable Value, a state-owned enterprise that holds centralised property sales and valuation information across the country.

4.1. Dunedin City

Dunedin City Council supplied a Geographic Information Systems (GIS) map layer identifying areas of soil types potentially susceptible to liquefaction. This map forms the basis of the information reported to prospective property buyers in LIMs (Soils and Foundations, 1993). Areas affected by liquefaction potential are all situated on flat land close to the city centre. In order to provide an acceptable control group for properties in these areas, we use sales records from non-liquefaction-prone areas of the inner suburbs only of the city. These areas are shown by the schematic map in figure 4.1.

Figure 4.1. Sampling areas for property sales by liquefaction potential in Dunedin City



The sampling procedure we requested from PropertyIQ is designed to facilitate repeat sales estimation. We asked for records of properties that meet both of the following conditions:

1) the property has a sale record in the post-earthquake period (since 1 December 2010)[14]
2) the property also has at least one previous sale record in the pre-earthquake period (from 1 January 1990 to 31 August 2010).

For the liquefaction-prone zone, we have all sales data (since 1990) for qualifying properties. As the non-liquefaction-prone zone is larger and contains more records, we obtained a 50% random sample of qualifying properties in the post-earthquake period and all previous sales for the selected properties in the pre-earthquake period.

[14] Some sales that were completed after early September 2010 may have been agreed to before the earthquake. Therefore, the weeks between the earthquake and 1 December 2010 are excluded from our definition of the post-earthquake period.

Each sale record includes an identifier for the property, the date of sale and the sale price, the property's assessed value (and the date of its latest valuation) and a number of variables that characterise the age, structure and condition of the property and its immediate surroundings. With a few exceptions (namely, land area and floor area), we create categorical variables for these characteristics. We use information on construction year and the sale date to calculate the age of the property at the time of the sale, and we classify transactions by quarter. Finally, we group building construction type into three categories: brick, weatherboard and other. Summary statistics for key variables by liquefaction potential zone are provided in table A.1 of the appendix.

If a house was sold multiple times within a short period of time (either in the same quarter or in adjacent quarters), we keep only the record with the highest sale price – typically, this is for the latest sale. In addition, we discard observations where the ratio of the property's recorded sale price to its expected sale price (calculated as the most recent rated value adjusted by the urban centre's house price index) is less than 2/3 or larger than 3/2. As a result of imposing these conditions, some houses end up with a pattern of sales that makes them unsuitable for repeat sales estimation (this happens if a house does not have any pre-earthquake sales or any post-earthquake sales). We drop the remaining observations on these houses from the sample.

Implementing these data cleaning steps yields an unbalanced panel for Dunedin of 5,009 sales of 1,392 houses (over the period spanning 1990q1 to 2013q3). Of these houses, 469 are located within the liquefaction-prone area (1,733 sales). The temporal distribution of sales is shown in more detail in table 4.1. The majority of houses have a single post-earthquake sale and one to three pre-earthquake sales. However, some properties in the sample have been sold eight or more times.

Table 4.1. Distribution of repeat sales in Dunedin City

	post-EQ sales			
pre-EQ sales	1	2	3	Total
1	393	22	1	416
2	338	13	1	352
3	276	13	0	289
4	176	8	0	184
5	93	7	0	100
6	34	2	0	36
7	12	0	0	12
8	2	0	0	2
9	1	0	0	1
Total	1,325	65	2	1,392

Note: Rows represent the number of pre-earthquake sales and columns represent the number of post-earthquake sales of an individual house. Entries of the table show the number of houses with corresponding repeat sale patterns.

4.2. Hutt City

Geographic liquefaction potential information in the Wellington region has been released for public use by the Greater Wellington Regional Council (dataset, 2014). For Hutt City, the classification of liquefaction potential includes four categories: 'high', 'moderate', 'variable: low to high' and 'no potential'. These areas are illustrated in figure 4.2. We group the high, moderate and variable zones into a single liquefaction potential zone.[15]

As for Dunedin, PropertyIQ supplied data on properties in Hutt City that met both our conditions. For Hutt City, we have all sales records for qualifying properties going back to the beginning of 1990. The variables included in this dataset exactly match those in our Dunedin City sample, and are summarised in table A.1 (in the appendix).

We have a slightly extended dataset of sales for Hutt City with three additional quarters: the post-earthquake period runs through to 2014q2. To construct our main estimation sample, we proceed analogously to the Dunedin sample. After applying the same conditions, we are left with 12,688 sales of 4,076 houses. The average house in the Hutt City sample has been sold 3.11 times, while the average house in the Dunedin sample has been sold 3.60 times since early 1990. The temporal distribution of Hutt City sales is illustrated in table 4.2.

[15] We considered modelling all four liquefaction zones individually, but the high and moderate zones contain a relatively low number of property transactions.

Figure 4.2. Sampling areas for property sales by liquefaction potential in Hutt City

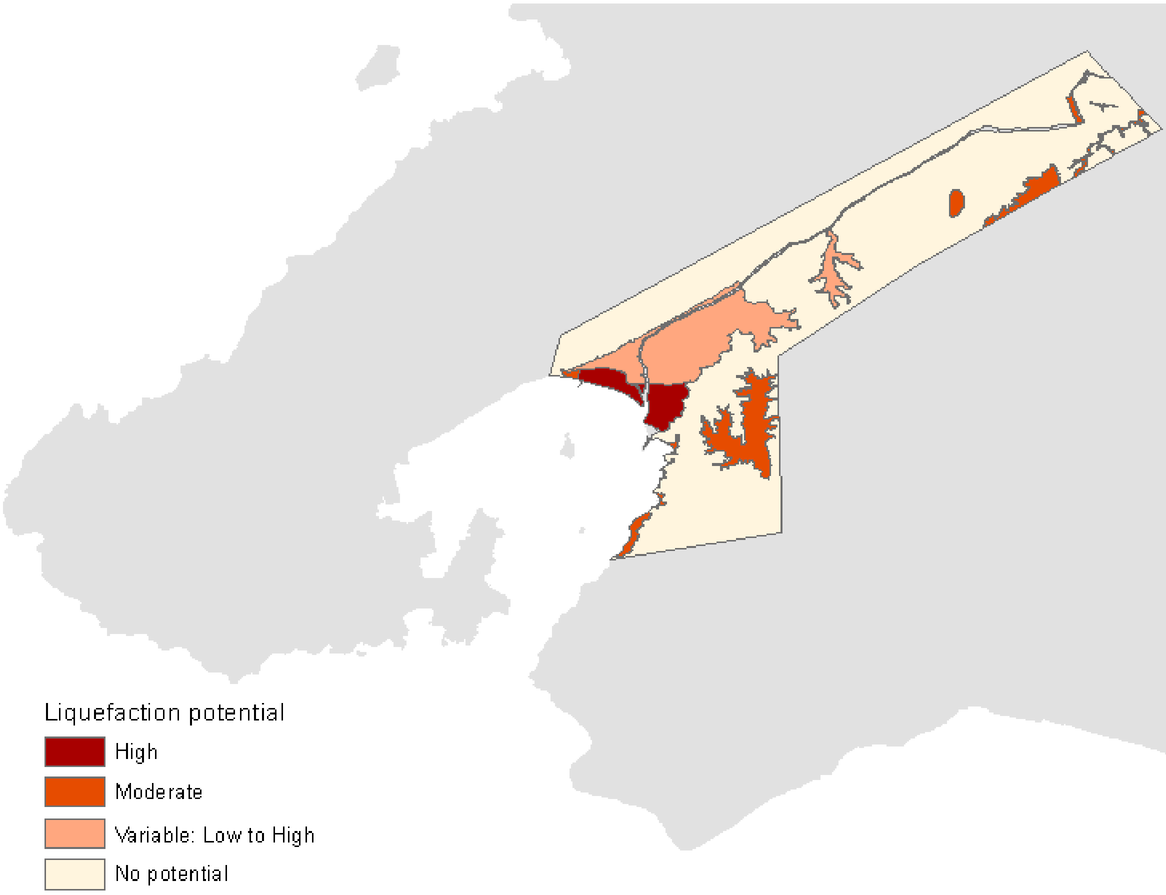


Table 4.2. Distribution of repeat sales in Hutt City

	post-EQ sales			
pre-EQ sales	1	2	3	Total
1	1,507	82	0	1,589
2	1,213	55	1	1,269
3	718	38	0	756
4	317	13	0	330
5	99	3	0	102
6	19	1	0	20
7	7	1	0	8
8	2	0	0	2
Total	3,882	193	1	4,076

Note: Rows represent the number of pre-earthquake sales and columns represent the number of post-earthquake sales of an individual house. Entries of the table show the number of houses with corresponding repeat sale patterns.

Simple summary statistics of our data for Hutt and Dunedin cities can be used to test informally three of our maintained assumptions: (i) that people knew that seismicity is high in Hutt City and low in Dunedin City; (ii) that people knew that as a construction material, brick is in general less safe than weatherboard in areas of high seismicity; and (iii) that liquefaction potential was largely ignored in house construction and purchase decisions prior to the Christchurch earthquakes. Table 4.3 presents for each city the percentage of houses in our sample that are made of brick, weatherboard and other materials, and it breaks down these figures by liquefaction potential zone.

The table shows that only 11% of houses were built of brick in Hutt City compared with 28% of houses in Dunedin. Weatherboard houses comprise 62% of Hutt houses compared with 41% of Dunedin houses. Thus the area of high seismicity had a strong net positive balance of houses in the safer construction material. If people had known of (or responded to) the risks of liquefaction, we may have expected to see a greater reluctance to build in brick on liquefaction-prone land but that is not the case. These descriptive statistics are consistent with our maintained assumptions about the knowledge of and reaction to earthquake-related risks across the two cities.

Table 4.3. Distribution of earthquake-related characteristics (in percentages)

		Construction material			
Area		Brick	Other	Weatherboard	Total
Dunedin:	overall	27.6	31.5	40.9	100.0
	liquefaction	32.1	29.4	38.5	100.0
	non-liquefaction	19.1	35.4	45.5	100.0
Hutt City:	overall	11.1	26.8	62.1	100.0
	liquefaction	12.3	28.6	59.2	100.0
	non-liquefaction	9.6	24.4	66.0	100.0

5. Results

To facilitate the interpretation of results and comparisons across the models, we estimate nested specifications for each study area, keeping the same sample across specifications.

5.1. Dunedin City

Column [1] of table 5.1 reports estimation results for key variables from an hedonic regression. Table A.2 in the appendix reproduces the complete set of hedonic results, including parameter estimates for house characteristics.[16] Columns [2] and [3] contain estimation results from

[16] Due to the large number of parameters involved, we do not reproduce estimates of the time- and suburb-specific effects.

two repeat sales specifications.[17] We describe the structure of each model, and then discuss the main estimation results. (We briefly discuss key findings with respect to non-earthquake related property characteristics for both cities when presenting the hedonic estimation results for Hutt City in the next subsection.) All three models test for a permanent effect on risk pricing following the first earthquake (EQ); we introduce time-varying effects subsequently.

Table 5.1. Dunedin City estimation results (main parameters only)

Variable	[1]	[2]	[3]
Quarter	YES	YES	YES
Suburb	YES	NO	NO
House fixed effect	NO	YES	YES
Suburb x time	NO	NO	YES
Liquefaction	-0.0119	(omitted)	(omitted)
	(0.0298)		
Liquefaction x Post EQ	0.0312**	0.0242	0.0430
	(0.0156)	(0.0176)	(0.0270)
Construction			
Brick	0.0567***	-	-
	(0.0161)		
Other	0.0213	-	-
	(0.0173)		
Weatherboard	(base)	-	-
Construction x Post EQ			
Brick	-0.0240	-0.0203	-0.0267
	(0.0166)	(0.0183)	(0.0180)
Other	-0.0210	-0.0193	-0.0163
	(0.0182)	(0.0194)	(0.0190)
Weatherboard	(base)	(base)	(base)
Observations	5,009	5,009	5,009
Houses	1,392	1,392	1,392
R-squared	0.819		
AIC	1,994.2	-1,026.8	-1,026.5
BIC	3,245.9	-218.5	16.6

Note: Robust standard errors are shown in parentheses. Asterisks indicate statistical significance (*** p<0.01, ** p<0.05, * p<0.1). Complete estimation results for model [1] are reproduced in table A.2 of the appendix.

In the hedonic model corresponding to column [1], log house price is regressed on quarter and suburb dummies and a range of variables controlling for observed characteristics of a house. Estimates for the suburb indicators act as area-specific intercepts, allowing the average house price to vary systematically by suburb. They thereby account for overall differences in the desirability of living in various suburbs, whether these differences arise from the state of transportation

[17] The R^2 statistic is not shown for the repeat sales models as it is not comparable to the hedonic model.

infrastructure, socio-economic differences, the availability of environmental amenities or other factors.

We include an indicator for location within the liquefaction potential zone and also interact this variable with an indicator for the post-earthquake period to isolate sales on liquefaction-prone land that occurred following the first Christchurch earthquake. In a similar manner, we include indicators for construction type and interact these variables with the post-earthquake indicator. This enables us to consider relative price changes associated with brick houses and houses of other non-weatherboard construction that occurred after the first earthquake.

Columns [2] and [3] contain estimation results for two specifications of the repeat sales model. Each of them includes individual quarter and house fixed effects. Recall that the estimation of a house fixed effect means that it is not possible to identify the effect of (unchanging) house characteristics or other time-constant variables in these models.[18] For example, suburb indicators are not included directly in the repeat sales models because suburb definitions are constant in our dataset. Suburb-specific time effects, on the other hand, can still be estimated. The model in [3] extends [2] by adding a linear time trend for each suburb. These spatially differentiated trends can account for situations in which the relative desirability of a suburb changes systematically over time.

Our focus is on whether some properties experienced a different post-earthquake impact than others. We test this via the estimates for the interaction terms involving our earthquake-related variables and the post-earthquake indicator. A finding that the impact varies systematically by liquefaction zone or construction type would support the hypothesis that risk perceptions were affected by the earthquakes.

Using the hedonic model (column 1), we do not find evidence for a pre-existing liquefaction risk discount in Dunedin City: the parameter estimate for liquefaction potential is negative, but not statistically significant. Furthermore, none of the three models suggests that the earthquakes (or the change in the wording of the cautionary advice on LIM reports) had a negative effect on house prices within the liquefaction potential zone of Dunedin. On the contrary, the parameter estimates for the interaction of the liquefaction and post-earthquake variables are positive (implying that properties in the liquefaction potential zone experienced a larger

[18] Variables for property attributes, including construction type, are included in both repeat sales models to control for the limited number of houses having attributes that change between two sales. The parameter estimates for these variables are based only on those observations that involve changing attributes, and do not have the same intuitive interpretation as in the hedonic model. Consequently, they are not reported. We have also estimated the model in column [3] dropping all houses that have characteristics that change over the sample, and the results remain robust in terms of sign and significance.

proportionate increase in price over the post-earthquake period than did other properties in the sample), but this effect is not significant in the repeat sales models, which better control for house characteristics.

With respect to building construction, estimation results from the hedonic model suggest that there is a (pre-existing) price premium of 5.7% associated with brick houses in Dunedin. Following the earthquakes, there is some indication that this premium may have fallen. However, while the post-earthquake parameter estimates for brick and other non-weatherboard construction are consistently negative, they are never statistically significant.

5.2. Hutt City

The three models shown in table 5.2 are analogous to the Dunedin City specifications: column [1] contains the results from the hedonic regression and columns [2] and [3] contain estimation results from the two repeat sales models.

Table A.2 in the appendix includes parameter estimates for property characteristics for Hutt City and Dunedin City. We discuss these results briefly to confirm that our data are reliable. Most of the results are statistically significant and confirm economic intuition. As expected, larger houses tend to be more expensive. Ceteris paribus, houses with more bedrooms command a higher price, as shown by the increasingly positive estimates for the bedroom number indicators. Moreover, positive estimates for the interaction of these variables with floor area indicate that for a given number of bedrooms, a higher floor area leads to a higher price. This impact is diminishing in the number of bedrooms: a one square metre increase in floor area has a lower impact on (log) house price for a property with more bedrooms. Likewise, the number of garages and the presence of a deck or a driveway tend to affect house price in expected ways. In general, property values also reflect the age and condition of the house. A comparison of results across the two columns of table A.2 suggests that the age discount is lower in absolute value in Hutt City than in Dunedin. It also reaches its maximum sooner. That is, the estimates indicate that houses older than about three to four decades do not depreciate in value further in Hutt City. These observations may signal that older neighbourhoods in Hutt City have other desirable characteristics that are not captured by the suburb indicators and other covariates. The parameters for building and roof condition, modernisation and the quality of surroundings have the expected sign. The estimates for terms characterising the nature and quality of the view from the property suggest that moderate and wide water views significantly contribute to the value of a house in Hutt City. Previous studies have also demonstrated a premium for water views (Benson et al., 1998; Samarasinghe and Sharp, 2010).[19] Finally, all else equal, houses built on a level piece of land tend to be more expensive than houses built on sloping terrain.

Table 5.2. Hutt City estimation results (main parameters only)

Variable	[1]	[2]	[3]
Quarter	YES	YES	YES
Suburb	YES	NO	NO
House fixed effect	NO	YES	YES
Suburb x time	NO	NO	YES
Liquefaction	0.0497***	(omitted)	(omitted)
	(0.00910)		
Liquefaction x Post EQ	-0.00634	-0.0108**	-0.0138**
	(0.00521)	(0.00495)	(0.00641)
Construction			
Brick	0.000814	-	-
	(0.00697)		
Other	-0.0272***	-	-
	(0.00609)		
Weatherboard	(base)	-	-
Construction x Post EQ			
Brick	0.000199	-0.00290	0.00452
	(0.00693)	(0.00656)	(0.00657)
Other	0.00100	0.00233	0.00618
	(0.00595)	(0.00548)	(0.00531)
Weatherboard	(base)	(base)	(base)
Observations	12,688	12,688	12,688
Houses	4,076	4,076	4,076
R-squared	0.931		
AIC	-11,354.3	-23,726.3	-24,367.1
BIC	-9,812.5	-22,638.8	-22,929.5

Note: Robust standard errors are shown in parentheses. Asterisks indicate statistical significance (*** p<0.01, ** p<0.05, * p<0.1). Complete estimation results for model [1] are reproduced in table A.2 of the appendix.

The hedonic regression for Hutt City reveals that houses located in the liquefaction potential zone initially cost around five percent more than similar houses elsewhere in the city. While this difference in property values cannot be explained by differences in observed house or suburb characteristics, we do not interpret this parameter in a causal sense. It is likely that the positive estimate reflects one or more unobservables which are accounted for in the repeat sales specifications but that are omitted from the hedonic regression. The size of the liquefaction premium decreased after the first earthquake as evidenced by the negative estimates for the

[19] It is interesting to note that without the inclusion of suburb indicators, the magnitude of these parameter estimates increases by nearly an order of magnitude. This likely happens because of the geographic definition of suburbs: some areas offer better views on average than others, and the suburb indicators capture some of the variation associated with views.

liquefaction interaction term in all three models. Notably, the decrease is statistically significant (at the 5% level) in the two repeat sales models.

Unlike in Dunedin, there does not appear to be a price premium associated with brick houses relative to weatherboard in Hutt City (while other construction types are seen as less desirable, ceteris paribus). A potential explanation for these findings is that non-weatherboard construction has always been perceived as less safe in Hutt City due to the larger and well-known seismicity of the Wellington region. This view is consistent with our earlier observation that a much smaller proportion of houses in our sample is built from brick in Hutt City than in Dunedin. However, it is also possible that unobserved (in the data) differences between building styles or other factors are responsible for the contrasting findings regarding construction type in our two study areas within the hedonic regression.[20] There is no evidence that the earthquakes had an impact on the value placed on alternative construction types in Hutt City. All post-earthquake construction type estimates are small in absolute value and are not statistically significant.

We evaluate the models more formally by comparing the Akaike Information Criterion (AIC) and the Bayesian Information Criterion[21] (BIC) for each specification: the preferred model minimises the AIC value or the BIC value. Both criteria apply to nested models and measure goodness of fit while taking into account the complexity of the model. The BIC introduces a larger penalty term for the number of parameters than the AIC, so tends to pick more parsimonious specifications. As expected, the repeat sales models outperform the hedonic model according to each criterion in both study areas. In Dunedin, model [2] performs slightly better, while in Hutt City, the more complete specification in [3] is preferred.

5.3. Time-varying Risk Premia

We test for a time-varying impact on risk perceptions following the earthquakes. The post-earthquake period encompasses twelve quarters in our Dunedin sample and fifteen quarters in the Hutt City sample. The liquefaction- and construction-related post-earthquake parameter estimates presented above represent the average impact over each of these periods. If there were a transient effect only, then consideration of the average effect over the full post-earthquake period may not provide an accurate indication of changes in risk pricing (Gallagher, 2014; Bin and Landry, 2013).

[20] It is also possible that the hedonic estimates for pre-existing risk discounts are biased toward zero because of correlation between suburbs and the earthquake-related variables (e.g. if suburb boundaries follow natural features of the geography that also affect liquefaction potential). We have run additional estimates that restrict the sample to include only suburbs that have observations from both liquefaction and non-liquefaction zones. The results do not affect any of our conclusions in relation to the sign or significance of changes in the post-earthquake risk premia.

[21] The BIC is alternatively known as the Schwartz Information Criterion (SIC).

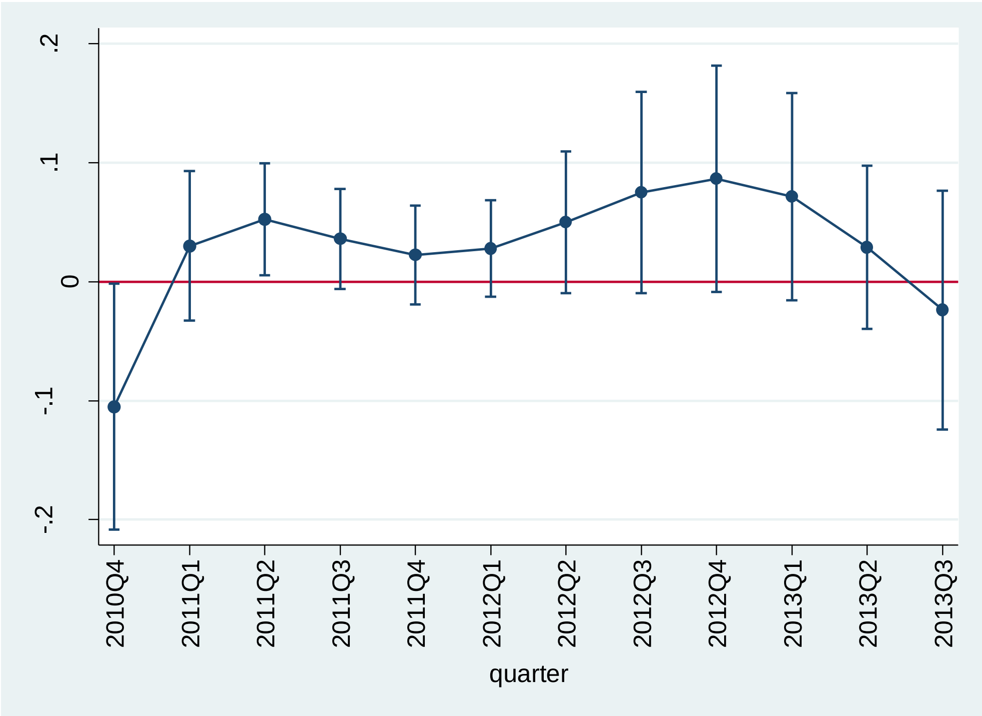
We therefore estimate additional specifications that allow for a non-constant post-earthquake impact. These regressions are based on the repeat sales model as specified in column [3] of tables 5.1 and 5.2, but with each post-earthquake interaction replaced by a new set of terms that allows for (smoothly-shaped) flexibility in risk pricing.

We allow the post-earthquake impact to change over time according to a quintic function (a polynomial of degree five).[22] This approach is implemented through the interaction of the indicators for liquefaction potential, brick construction and other construction with terms involving the first through fifth powers of a time variable whose value indicates the number of quarters that have elapsed since the first earthquake (and is zero for all quarters preceding the earthquake). We present estimation results for the liquefaction-related parameters graphically in figures 5.1 and 5.2. The estimated impacts for construction types are close to zero (and insignificant) in both cities throughout the post-earthquake period and so are not presented. The graphs show the estimated marginal price impact of being situated on liquefaction potential land, representing the estimated change in risk discount through time relative to the pre-earthquake risk premium. The point estimates are presented along with the 90% confidence interval evaluated at each quarter.[23]

[22] The quintic parameterisation allows for a high degree of flexibility while smoothing out some of the quarter-to-quarter noise in the data.

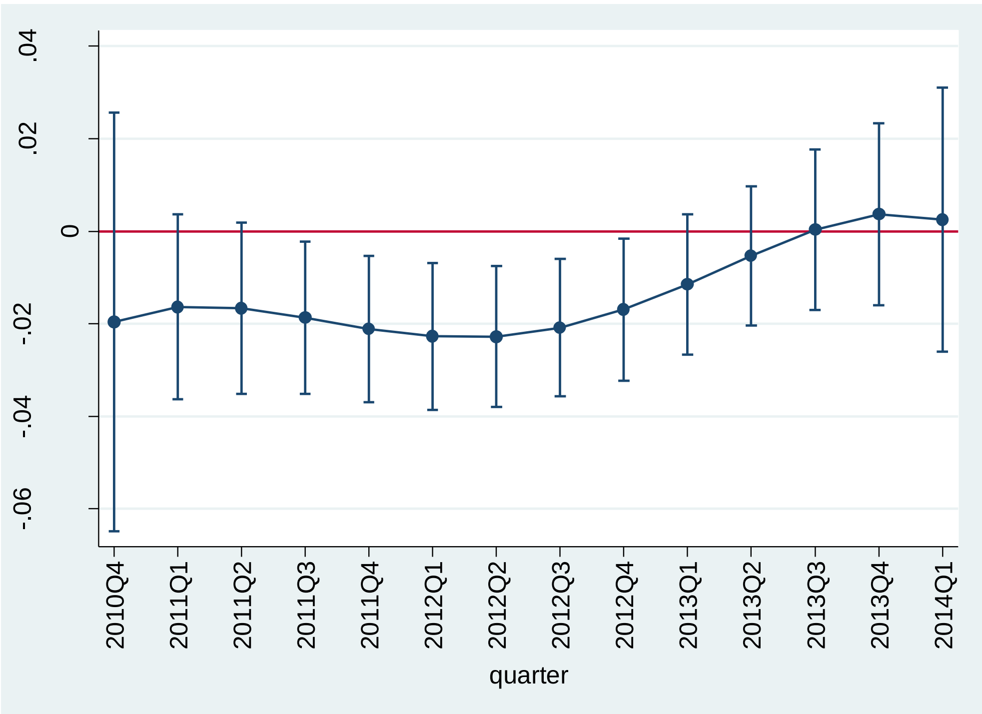
[23] The first and last post-earthquake quarters are partial quarters in our sample; they consequently tend to have wider confidence intervals. The second quarter of 2014, in particular, contains few observations for Hutt City. Figure 5.2 omits this quarter for the sake of visual clarity.

Figure 5.1. Estimated post-earthquake risk discount for liquefaction: Dunedin City



Note: Vertical bars represent the 90 percent confidence interval.

Figure 5.2. Estimated post-earthquake risk discount for liquefaction: Hutt City



Note: Vertical bars represent the 90 percent confidence interval. The last quarter, 2014Q2, is not shown.

In Dunedin City, the estimated marginal impact of liquefaction potential is negative and just significant at the 10% level in the first post-earthquake quarter. The marginal impact then rises and remains positive (but not statistically significant) during most remaining quarters. These time-varying results are broadly consistent with the time-invariant results that showed a statistically insignificant (positive) impact on the risk premium associated with liquefaction potential for Dunedin.

By contrast, in Hutt City, the estimated risk discount is negative for the first eleven post-earthquake quarters. The marginal impact is statistically significant at the 10% level in six of these quarters (and statistically significant at the 5% level in four of those quarters).[24] These results indicate that in Hutt City, the liquefaction risk discount was approximately two percent for around two years following the earthquakes, but this discount had entirely disappeared after the third year.

The results shown in Figure 5.2 demonstrate the importance of testing for a time-varying post-earthquake risk premium. The time-invariant results showed a statistically significant decline of approximately 1.4% in the price attached to a house on liquefaction-prone land in Hutt City. However, this represents an incomplete analysis of the earthquake's impact. Instead, the time-varying estimates show that houses situated on liquefaction-prone land fell in price by around 2% for two years following the earthquakes but that this discount dissipates with time and is back to zero within three years of the first earthquake.

6. Conclusions

In this paper, we treat the Canterbury earthquake sequence as a source of new risk information to home buyers in New Zealand and compare pre- and post-earthquake sales of residential properties that are exposed to varying levels of seismic risks in two urban areas that were not directly affected by the earthquakes. One of our study areas, Hutt City, has a much higher degree of background seismicity than the other, Dunedin City. A seismic event may affect homeowners directly through two channels: liquefaction of the land and through the type of building construction. Risks associated with construction type (especially brick versus weatherboard) have been well known in New Zealand since at least 1855. By contrast, the importance of liquefaction potential, while known and documented by scientists, was not widely appreciated by homeowners and nor did it impact on decisions by banks or insurers in relation to the housing market. Consequently, within our difference-in-difference-in-difference approach we

[24] These results also hold with the more conservative sample that excludes observations with changing property characteristics.

hypothesised that risk premia associated with construction type will not have changed following the earthquake in any region, while the price of houses situated on liquefaction potential land will have fallen after the earthquake in an area that is subject to high seismicity but not in an area subject to minimal seismicity.

We test these hypotheses using hedonic and repeat sales regressions. The hedonic regressions show no explicit discount for liquefaction or for brick construction in Dunedin or Hutt Cities prior to the Christchurch earthquakes, although the inability to account for unobservables makes it difficult to draw strong conclusions in this respect. The small proportion (11%) of brick houses in high seismicity Hutt City relative to low seismicity Dunedin City (28%) and the high proportion of weatherboard houses in Hutt (62%) compared with Dunedin (41%) indicates that brick (weatherboard) houses were perceived to be more (less) risky in an earthquake-prone area prior to the Christchurch earthquakes.

Following the Christchurch events, we find no significant change in the risk premium attached to non-weatherboard houses in either Hutt City or Dunedin City. Furthermore, we find no indication of a change in the risk premium associated with liquefaction potential in the low seismicity city (Dunedin). By contrast, we find a significant increase in the discount associated with liquefaction-potential land in the high seismicity city (Hutt). However the risk premium (of approximately 2%) lasts for only about two years and has fully dissipated after three years. Such a transitory impact is consistent with other recent research on the effects of uncertain and infrequently observed hazard events (Gallagher, 2014; Bin and Landry, 2013), albeit our study differentiates across risk types and risk potential in ways that previous studies have not.

The insignificance of changes in the risk premium associated with construction type in both cities and with liquefaction potential in Dunedin is consistent with our hypotheses, as is the increased premium associated with liquefaction potential in Hutt City. One explanation for the observed temporary effect of the raised liquefaction risk premium in Hutt City is that, behaviourally, recent events have greater salience than do more distant events. People adapt their risk perceptions in the light of recent events, since the importance of a risk such as liquefaction is prominent in the media, and so cannot be ignored. As media coverage declines, and in the absence of recurring liquefaction events, the salience of this risk declines and the desirability associated with observable features of a house may crowd out the unseen risk associated with liquefaction potential. In this respect, the above ground reminder of the risks posed by brick construction may differ from the below ground presence of liquefaction potential in terms of salience.

An alternative explanation for the transient post-earthquake price reduction for properties built on liquefaction-prone soil in Hutt City is that prospective purchasers may have been unsure as to whether future insurance availability or insurance premiums would be affected by the liquefaction potential status of a property. If there was uncertainty about insurance availability or a prospect of higher premiums, then demand for liquefaction-prone properties would have decreased leading to a price discount. To date, insurance companies have not made any differentiation in policy availability or rates with respect to liquefaction potential for houses, and they have not indicated any intention of doing so in the future. With the passage of time, purchasers may therefore have (rationally) discounted these insurance-related risks, reversing the initial discounts relating to insurance uncertainty.

However, given our difference-in-difference-in-difference results, for this to be an explanation of the contrasting outcomes in Hutt versus Dunedin cities, prospective purchasers would have had to surmise that insurance companies – which hitherto had quite undifferentiated approaches to risk pricing across houses – might change their insurance structure to differentiate not only between houses built on high versus low liquefaction potential land but also according to how these liquefaction potentials interact with seismicity. We cannot rule out the possibility that this thought process underlay the time-varying risk premium, but we regard it as unlikely given insurance firms' actual behaviour before and after the earthquakes.

If the cognitive dissonance explanation underlies the dissipation of the post-earthquake risk premium, there may be a case for a public policy role, as suggested by Akerlof and Dickens. At a minimum, greater highlighting of liquefaction risk for a house located in a high seismicity area (on the LIM report, for instance) may be warranted so as to increase the ongoing salience of the risk to prospective purchasers. Alternatively, given the New Zealand government's ownership of EQC (the provider of natural disaster insurance to owners of residential properties), government could require EQC to differentiate its premia according to the risk of seismicity combined with liquefaction potential. These interventions may lead to a more efficient pricing of houses (ultimately affecting development and location decisions) in the presence of behavioural or other features that lead at least some people to downplay known risk elements.

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Appendix

Table A.1. Summary statistics

	Dunedin City		Hutt City	
Variable[1]	Liquefaction = 0	Liquefaction = 1	Liquefaction = 0	Liquefaction = 1
Number of houses	923	469	2,314	1,762
Number of sales				
Pre-earthquake	2,317	1,231	4,823	3,594
Post-earthquake	959	502	2,430	1,841
Land area (mean)	0.06	0.04	0.08	0.05
Floor area (mean)	140.79	121.01	135.10	125.09
Bedrooms				
1	18	4	17	22
2	407	227	463	656
3	1,837	1,107	4,601	3,444
4	750	334	1,805	1,074
5+	264	61	367	239
Age (at time of sale)				
0-9	52	11	594	276
10-19	76	15	729	323
20-29	130	30	1,184	423
30-39	240	34	1,478	505
40-49	360	48	1,431	698
50-59	395	62	1,031	836
60-69	400	129	480	840
70-79	396	309	170	686
80-89	395	422	90	498
90-99	344	342	53	195
100+	488	331	13	155
Construction				
Brick	1,052	331	890	520
Other	962	614	2,071	1,326
Weatherboard	1,262	788	4,292	3,589
Building condition				
Average	1,985	1,151	5,116	4,420
Fair / poor	155	133	23	90
Good	1,136	449	2,114	925
Roof construction				
Other	89	9	175	131
Steel / G-iron	2,049	1,361	3,937	2,882
Tile profile	1,138	363	3,141	2,422
Roof condition				
Average	1,786	880	5,246	4,325
Fair / poor	196	169	28	65
Good	1,294	684	1,979	1,045
Deck				
No	1,728	1,132	2,739	2,850
Yes	1,548	601	4,514	2,585

Driveway				
No	1,671	1,088	714	720
Yes	1,605	645	6,539	4,715
Garages				
None	1,091	685	679	734
1	1,672	856	3,333	2,803
2	444	189	2,861	1,679
3+	69	3	380	219
House type				
Bach	15	0	31	5
Post-war bungalow	1,083	184	5,777	2,542
Contemporary	39	0	211	27
Cottage	109	70	54	78
Pre-war bungalow	855	842	305	1,350
Quality bungalow	63	2	356	183
Quality old	66	21	38	115
Spanish bungalow	42	14	64	88
State rental[2]	107	0	368	698
Townhouse	0	5	3	0
Villa	897	595	46	349
View x View scope				
Other x Moderate	771	15	1,023	144
Other x Slight	674	11	608	150
Other x Wide	490	11	498	31
Water x Moderate	246	0	375	33
Water x Slight	38	0	161	34
Water x Wide	86	0	479	25
No view	971	1,696	4,109	5,018
Contour				
Easy / moderate fall	756	13	703	109
Easy / moderate rise	989	14	1,046	194
Level	924	1,706	4,745	5,109
Steep fall	213	0	221	7
Steep rise	394	0	538	16
Surroundings				
Above average quality	347	57	1,136	406
Average quality	2,116	462	6,009	4,513
Below average quality	797	1,205	37	383
Poor quality	6	0	0	7
Superior quality	10	9	71	126
Modernisation				
No	1,730	852	4,461	2,671
Yes	1,546	881	2,792	2,764

Notes:
[1] Entries in the table, unless otherwise indicated, represent the number of sales by house characteristic.
[2] All sales in our sample represent private purchases of residential freehold properties. Houses classified as 'state rental' in our dataset are not actually state-owned. However, they were once built by the government and represent a distinctive architectural style.

Table A.2. Hedonic model estimation results (complete)

Variable	Dunedin City	Hutt City
Quarter	YES	YES
Suburb	YES	YES
Liquefaction	-0.0119	0.0497***
	(0.0298)	(0.00910)
Liquefaction x Post EQ	0.0312**	-0.00634
	(0.0156)	(0.00521)
Construction		
Brick	0.0567***	0.000814
	(0.0161)	(0.00697)
Other	0.0213	-0.0272***
	(0.0173)	(0.00609)
Weatherboard	(base)	(base)
Construction x Post EQ		
Brick	-0.0240	0.000199
	(0.0166)	(0.00693)
Other	-0.0210	0.00100
	(0.0182)	(0.00595)
Weatherboard	(base)	(base)
Land area	1.135***	0.596***
	(0.257)	(0.0651)
Bedrooms		
1	(base)	(base)
2	0.205**	0.0771
	(0.0898)	(0.130)
3	0.236***	0.263**
	(0.0773)	(0.128)
4	0.347***	0.337***
	(0.0845)	(0.128)
5+	0.592***	0.456***
	(0.102)	(0.134)
Bedrooms x Floor area		
1	0.00547***	0.00588***
	(0.000713)	(0.000898)
2	0.00320***	0.00446***
	(0.000651)	(0.000289)
3	0.00299***	0.00305***
	(0.000242)	(0.000109)
4	0.00249***	0.00276***
	(0.000297)	(0.000102)
5+	0.00153***	0.00223***
	(0.000317)	(0.000192)
Age		
0-9	(base)	(base)
10-19	-0.0811**	-0.0959***
	(0.0390)	(0.00885)
20-29	-0.245***	-0.135***
	(0.0423)	(0.00900)
30-39	-0.292***	-0.162***
	(0.0393)	(0.00977)
40-49	-0.324***	-0.184***
	(0.0385)	(0.0106)

Age		
50-59	-0.342***	-0.166***
	(0.0408)	(0.0115)
60-69	-0.375***	-0.140***
	(0.0422)	(0.0131)
70-79	-0.386***	-0.114***
	(0.0449)	(0.0164)
80-89	-0.397***	-0.126***
	(0.0468)	(0.0188)
90-99	-0.431***	-0.0705***
	(0.0479)	(0.0245)
100+	-0.428***	0.0157
	(0.0517)	(0.0276)
Building condition		
Average	(base)	(base)
Fair / poor	-0.0505	-0.0445*
	(0.0446)	(0.0238)
Good	0.0544***	0.0135
	(0.0142)	(0.00872)
Roof construction		
Other	-0.0233	-0.00176
	(0.0463)	(0.0152)
Steel / G-iron	(base)	(base)
Tile profile	0.0484***	0.0185***
	(0.0130)	(0.00455)
Roof condition		
Average	(base)	(base)
Fair / poor	-0.0893	-0.0315
	(0.0576)	(0.0223)
Good	-0.00231	0.00929
	(0.0130)	(0.00866)
Deck	0.0127	0.0410***
	(0.0126)	(0.00427)
Driveway	0.0251*	0.0318***
	(0.0139)	(0.00713)
Garages		
None	(base)	(base)
1	0.0713***	0.0610***
	(0.0140)	(0.00691)
2	0.118***	0.0930***
	(0.0191)	(0.00755)
3+	0.0493	0.0956***
	(0.0428)	(0.0107)
House type		
Bach	-0.286***	-0.0758*
	(0.0959)	(0.0393)
Post-war bungalow	(base)	(base)
Contemporary	0.152**	0.0395**
	(0.0657)	(0.0177)
Cottage	-0.0204	-0.121***
	(0.0422)	(0.0279)
Pre-war bungalow	0.128***	0.00913
	(0.0235)	(0.0120)

House type		
Quality bungalow	0.0327	0.0635***
	(0.0506)	(0.0133)
Quality old	0.154***	0.236***
	(0.0495)	(0.0297)
Spanish bungalow	0.0576	-0.0335
	(0.0435)	(0.0209)
State rental	-0.149***	-0.0788***
	(0.0365)	(0.0108)
Townhouse	-0.136***	0.0770*
	(0.0459)	(0.0431)
Villa	0.127***	-0.0212
	(0.0314)	(0.0226)
View x View scope		
Other x Moderate	0.0174	0.0114
	(0.0198)	(0.00947)
Other x Slight	-0.00952	-0.00561
	(0.0203)	(0.0100)
Other x Wide	0.0249	0.00402
	(0.0237)	(0.0124)
Water x Moderate	0.000964	0.0444***
	(0.0333)	(0.0139)
Water x Slight	-0.0306	-0.00351
	(0.0784)	(0.0190)
Water x Wide	0.0586	0.0406***
	(0.0432)	(0.0144)
No view	(base)	(base)
Contour		
Easy / moderate fall	-0.0433**	-0.0261***
	(0.0187)	(0.00961)
Easy / moderate rise	-0.00678	-0.0331***
	(0.0192)	(0.00830)
Level	(base)	(base)
Steep fall	-0.0895***	-0.0530***
	(0.0308)	(0.0167)
Steep rise	-0.0297	-0.101***
	(0.0274)	(0.0130)
Surroundings		
Above average quality	0.0916***	0.0812***
	(0.0260)	(0.00848)
Average quality	(base)	(base)
Below average quality	-0.0712***	-0.0712***
	(0.0160)	(0.0127)
Poor quality	-0.288***	0.0175
	(0.0420)	(0.0977)
Superior quality	0.242***	0.178***
	(0.0930)	(0.0257)
Modernisation	0.0440***	0.0363***
	(0.0118)	(0.00466)
Constant	10.56***	10.86***
	(0.0961)	(0.130)
Observations	5,009	12,688
R-squared	0.819	0.931

Note: Robust standard errors in parentheses (*** p<0.01, ** p<0.05, * p<0.1).

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