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Using GIS to measure the impact of the Canterbury earthquakes on house prices in Christchurch, NZ

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Abstract

Purpose – Canterbury, New Zealand, experienced two significant earthquakes in 2010 and 2011 with a devastating impact on both houses and land. Negative media attention to the potential financial risks of living near or on the new Technical Category 3 (TC3) land or on land in a flood zone has fuelled the perception of uncertainty over the negative property price impacts. This research aims to determine if residents' perceptions of the risks associated with various types of land zones (e.g. TC1, TC2 and TC3) are reflected in property prices.

Design/methodology/approach – This research analyses sale price patterns and the relationship between sale prices and house characteristics before and after both earthquakes. A three-step approach was taken by applying: an average trend analysis, Geographic Information Systems' (GIS) hotspot analysis to identify possible spatial differentiations between the before and after-effects of the earthquakes and hedonic modelling to quantify the effect of house characteristics on sale price while controlling for and comparing three land zones (TC1 to TC3).

Findings – The data suggest that average sale prices increased after both quakes in TC1 and TC2 in contrast to TC3 zones, while close to 8,000 structures were demolished in red zones from 2010-2013 (supply was reduced). The econometric modelling suggests that higher sale prices are achieved by: newer houses across all land zones and more recent sale agreements only in TC1 and TC2 zones. Other observations include the effect of certain exterior façade materials on sale prices on the overall data set and in the individual TC1 and TC3 zones. In conclusion, the results suggest that although caution might exist for the TC3 zone, the quality of the house can override the stigma attached to the TC3 zones.

Research limitations/implications – A confounding factor in the research was that approximately 7,800 homes were rezoned red and/or demolished between 2010 and 2013 changing the supply and demand balance. Further, banks and other lenders updated their requirements for new lending on properties in the Canterbury region, requiring a number of reports from professionals such as structural engineers, geotechnical engineers and valuers before any new lending would be approved. Additionally, immediately after the September and February earthquakes, there was a 21-day stand-down period for earthquake-cover in Canterbury and without adequate insurance cover banks would not advance mortgage money, causing a short-term slowdown in the residential property market.

Practical/implications – The outcomes of this research will be of interest to government agencies tasked with assessing compensation for affected property owners. For example, the Earthquake Commission (EQC) developed a *Diminution of Value Methodology for Increased Flooding Vulnerability* that formed the basis of a High Court declaratory judgment decision in December 2014 that cleared the way for the EQC to start settling

This paper is based on a conference paper titled "Using GIS to Measure the impact of the Canterbury earthquakes on house prices in Christchurch, NZ" which was presented by the authors at the 14th LARES International Conference. Dr Sandy Bond was affiliated with Flagler College at the time of writing this paper but has since moved and is currently affiliated with the Department of Finance, California State University, Fullerton, Fullerton, California, USA.

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properties with increased flooding vulnerability. The EQC methodology was informed by the results of similar studies to this one, from around the world. Homeowners and rating valuers will also be interested in the results to understand how house prices have been affected by market perceptions towards earthquake damage, particularly in the worst-affected areas.

Originality/value – This study fills a research void regarding the price impacts of residents' perceptions of the risks associated with various types of land zones that reflect the expected future liquefaction performance of the land.

Keywords Building performance, Risk analysis, Built environment, Compensation, Flooding, Earthquakes

Paper type Research paper

Introduction

Canterbury, New Zealand (NZ), experienced four significant earthquakes in 2010 and 2011. It was the 22 February 2011 6.3 M_W earthquake that caused the most significant damage in Christchurch (NZ's third largest city), killing 185 people, as it was centred only 10 km south-east of the centre of Christchurch. Significant liquefaction affected the eastern suburbs, but it was the lateral spread that caused much of the building damage (Tonkin and Taylor, 2013).

The city was not well prepared for these events, as they occurred along previously unknown fault lines. Bond (2015) provides an overview of the events and the legislation established to aid recovery. Under the Canterbury Earthquake Recovery Act 2011, the Canterbury Earthquake Recovery Authority (CERA) was established to lead the recovery effort. CERA has progressively mapped all of greater Christchurch land into land zones according to assessments of land and building damage and risk of liquefaction. The zones are: green (Go Zone) and include technical categories 1, 2 and 3 (TC1, TC2, TC3) (as shown on the map in Figure A1 – Appendix 1) where the repair/rebuild process is able to begin; red (No Go Zone) where land repair would be prolonged and uneconomic; and white (Unzoned) that included the central business district (CBD) or hillside land where geotechnical mapping and further assessments are underway. Because of increased flood risk, mostly in the red zone, and changed land levels, new flood zone maps were required.

The green zoned land on the flat has been assigned to three foundation technical categories based on the expected future liquefaction performance. The aim of these categories is to ensure appropriately engineered foundations. The categories indicate which properties will require site investigations to assess the foundation type needed to suit the specific ground conditions. The technical categories are as follows:

- TC1 (grey) is where future land damage from liquefaction is unlikely and a soil test should suffice.
- TC2 (yellow) is where minor to moderate land damage from liquefaction is possible in future significant earthquakes.
- TC3 (blue) is where moderate to significant land damage from liquefaction is possible in future significant quakes. TC3 land tends to have a thin crust and liquefiable (loose sand) layer below. There are around 28,000 properties in the TC3 areas, and around 12,500 homes in the TC3 areas have major foundation and pile damage that will require more investigation of the ground around them (CERA, 2012).

This paper builds on Bond's (2015) previous literature review and survey of residents' perceptions towards owning and living in residential property subsequent to the Canterbury earthquakes. The current research investigates how the stigma that may arise from these perceptions affects actual sale prices. In addition, the price impact of resident's attitudes towards the new technical categories is explored. The paper starts with a brief review of the literature on risk perceptions towards earthquakes and how stigma can negatively impact on a property's price. As the previous study by Bond (2015) outlines the literature on risk perceptions to natural hazards, this paper will focus primarily on the stigma that may arise from these perceptions by investigating risk from both social and economic perspectives. Next, the research is introduced and the results are presented. The paper concludes with a discussion of the results and implications of the research.

Literature review

There is a body of literature of how at-risk populations prepare for, respond to and adjust to natural hazards such as floods, tsunamis and earthquakes. Understanding how individuals perceive risks is important not only to effective disaster planning and communication, but in terms of this research, also to understanding how such perceptions are reflected in property market behaviour.

Risk perception towards earthquakes

Solberg *et al.* (2010) provide a review of the international literature on the social – psychological factors that shape human adjustments to seismic risk. Relevant to this research is the finding in relation to material risk (a scientifically derived probability estimate of future risk) of failure of buildings and soils during seismic activity, that type, height, age and perceived structural vulnerability of respondent's residences, as well as their knowledge of proximity to soft soils and faults, heighten risk perception.

McClure *et al.* (2011) conducted a study to help understand what motivates residents to take preparedness activities. They interviewed 380 residents in Christchurch (200), Wellington (100) and Palmerston North (80) to assess changes in their perceptions of the risk of earthquakes before and after the 2010 Darfield, Canterbury, earthquake. Before the Darfield earthquake, while Christchurch citizens reported being aware of civil defence messages about preparedness, they thought that these messages applied to others, not themselves, as Christchurch was not known to be vulnerable to earthquakes and so they were less prepared for them.

Property related stigma

According to Bell (1999), stigma is a "market-imposed penalty". As noted in Bond (2015), anything that might change the public's perceptions towards risk, including the influence of media attention, will alter the degree and duration of stigma. Sanders (1996) notes that stigma does reduce with time and will be greatest immediately after the damage or loss occurs, especially when the publicity about the hazards has been intense and ongoing (Kinnard and Dickey, 1995). Market conditions have also been shown to affect risk perceptions. For example, Jackson (2001) and Sanders (1996) have found that strong market demand reduces, or mitigates, lender and investor risk and weak demand increases or exacerbates their risk.

Specific to the Christchurch experience, there were a number of reports in the Christchurch news about the risks of buying TC3 property and reduced value of this category of property (Bond, 2015). For example, The Press (2012) reported that "Christchurch buyers are paying a premium for less-damaged areas while shunning trouble and uncertainty in the most damage-prone neighbourhoods". Bond (2015) surveyed Christchurch residents and confirmed the existence of stigma related to earthquake-affected property. Christchurch residents reported having strong reservations about buying TC 3 property, and would discount it by 20 per cent if they were to buy such land.

Christchurch property valuer, Edwards (2012), predicts that this stigma will reduce, as there is now more information regarding Earthquake Commission's (EQC) new acceptable foundation solutions and the time frames for assessing properties. In an attempt to allay uncertainty around the Canterbury residential rebuild and TC3 land, CERA produced a booklet "The TC3 Residential Rebuild" (Canterbury Earthquake Recovery Authority, 2012).

The estimation of the duration of stigma is as important as the measurement of its magnitude from a valuation perspective. However, to confirm any change to stigma, similar studies of similar design to allow comparison between them need to be conducted over time, and their results made public. The research reported below is a starting point for this process of ongoing research.

Methodologies advocated to study property price effects

A variety of methods to assess post-disaster changes in house prices is reported in the literature (Levy, 1984, 1986; Sanders, 1996). Hedonic pricing models, as introduced by Court (1939) and further developed by Freeman (1979) and Rosen (1974), appear to be the most popular. Briefly, this method assumes that the price of a property is determined by a number of key characteristics or attributes. Breaking down a property into its main characteristics allows the influence of each attribute on the total price to be determined. Wilhelmsson (2000) identifies four broad types of property factors that households normally take into account in the purchasing decision:

- *house characteristics* (number of bedrooms, square feet, attached garage, etc.);
- its *location relative to urban services* (such as school districts, jobs, etc.);
- *environmental attributes* (such as the view or slope of the yard); and
- the impact of *macroeconomic attributes* (such as the prevailing interest rate for mortgages).

The hedonic pricing model was the approach taken for the current study with the addition of Geographic Information Systems (GIS) to measure the distance to various technical categories of land and flood zones. The advent of GIS with its ability to spatially link property addresses with geographic coordinates has revolutionised hedonic modelling. In a review of hedonic modelling, Malpezzi (2003) observes:

> Perhaps one of the most exciting areas for extending hedonic models is making use of the spatial structure of the data, using the emerging technology of geographic information systems and spatial autocorrelation.

The need for exploring an issue from both qualitative and quantitative perspectives, as described by Bryman (1988), was the stimulus for undertaking the two separate studies: Bond's (2015) study that surveyed Canterbury residents' to determine their perceptions of risk towards owning and living in residential property subsequent to the earthquakes and the current study which uses a hedonic and GIS approach to analyse sale price trends.

Research

Methodology

The broad aim of this research is to identify residents' perceptions of the risks associated with various types of land zones[1] (or technical categories,) such as possible future liquefaction and/or flooding. These attitudes are quantitatively assessed through the analysis of the house characteristics/profiles (e.g. sales price, construction year, number of bedrooms, exterior and roof façade material and sell days) before and after the two area earthquakes (9/4/10 and the 2/22/11) while controlling for the three land zones.

Specifically, three distinctive approaches are used in this study:

(1) *Descriptive statistics:* Average and standard deviation trends and *t*-tests were applied among certain house characteristics for the overall Christchurch data set regardless of the land zones and then separately for each of the three designations (TC1, TC2 and TC3) both before and after the two quakes. This initial approach provided a first overview of the differentiations among the three designations regarding house characteristics and attitudes when accounting for the two quakes (Figure A2 – Appendix 2). Identifying the number of observations for each of the exterior and roof façade materials allowed the determination of the most common materials which were then considered for further analysis.

(2) *Spatial data analysis:* The application of GIS in this case allows: the visual representation of both the housing sales and the land zones throughout the study area before and after the two quakes (as seen in the data section – Figures 1 and 2) and the identification of spatial distribution patterns by using an optimized hotspot analysis, which applies the Getis-Ord Gi statistic (Figure A3 – Appendix 3) and shows the statistically significant clustering (hot-spot and cold spot). The resulting maps are based exclusively on house sale prices while accounting for the neighbouring houses. The benefit from this approach is the visual determination of areas with similar prices, while the three land zones are shown in the background.

(3) *Hedonic modelling:* This study applies an ordinary least square (OLS) regression model which explores the effect of certain house characteristics on sale prices before and after the two earthquakes in the following ways: the overall data set regardless of land zone and within each of the most popular land zones (TC1 through TC3) (Tables AI and AII – Appendix 4). All models were tested for possible multicollinearity and appropriate adjustments were made to avoid it. The model parameters are (equation 1) as follows:

$$\ln(saleprice) = a + \beta_1 Const.year_i + \beta_2 Bedrooms_i + \beta_3 Agr.Year_i + \beta_4 Sell\_days_i + \beta_5 Land\_area_i + \beta_6 ExteriorFacade_i + \beta_7 RoofFacade_i + \varepsilon \quad (1)$$

where: sale price is the price a property was sold for, const. year is the construction year of the structure, bedrooms is the number of bedrooms, agr. year is the agreement year from 2008 through 2012, sell_days is the number of days it took for a property to be sold, land area is the lot size in square metres, exterior façade refers to a variety of dummy variables which is recorded as 1 if the structure exterior façade is built with the material specified or otherwise zero, roof façade is similar to the exterior dummies with a value of 1 given to houses with the specified material. The determination of which façade material to include in the model was made based on the information derived from the descriptive statistics which highlighted the material most predominately used.

Data and transformations

The initial ArcGIS data set included residential transaction activity using data from the Real Estate Institute of NZ and an online sales system ValBiz by Headways Systems Ltd. A number of data fields were provided per house which can be grouped into two categories:

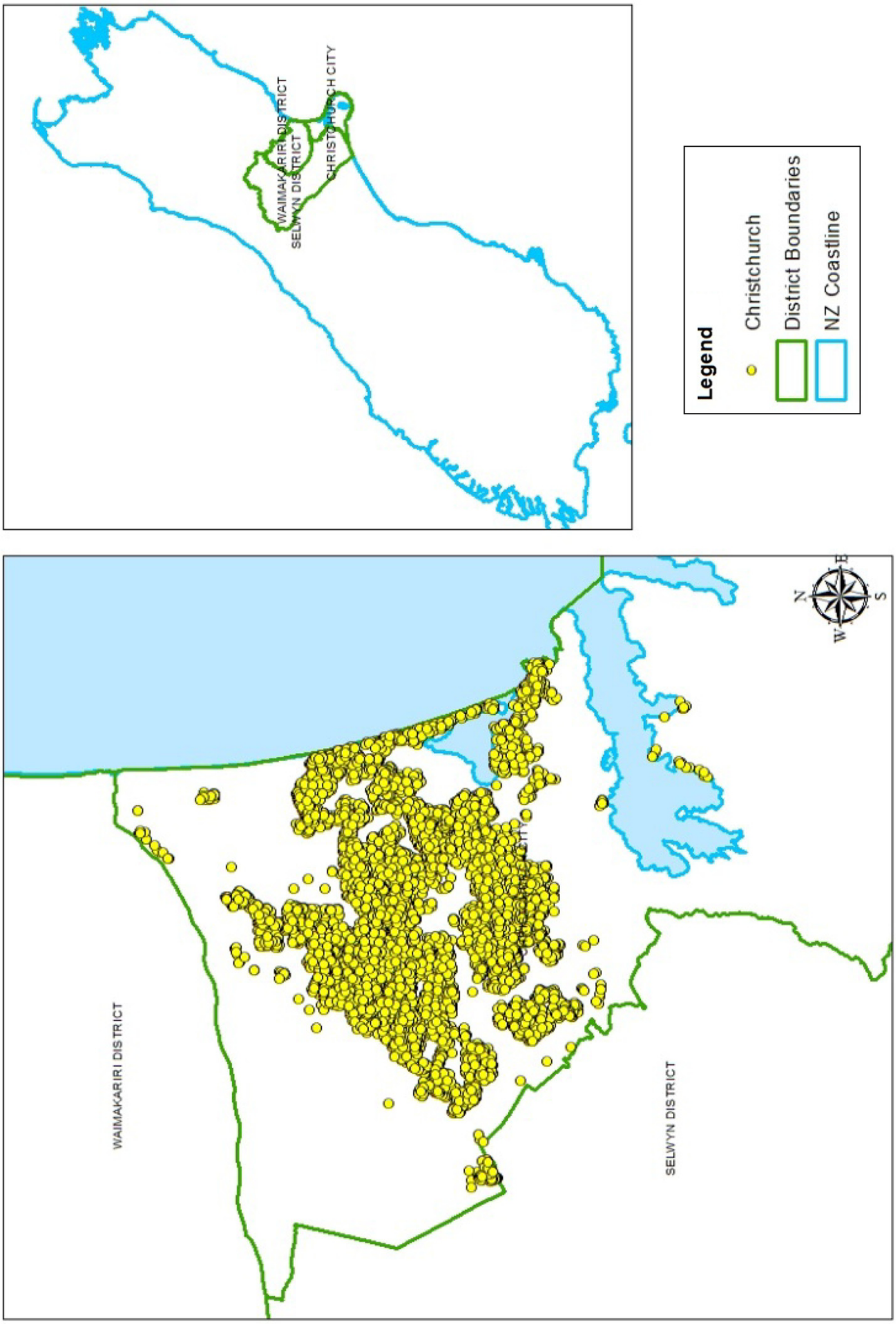

Figure 1.
Study area with house allocation

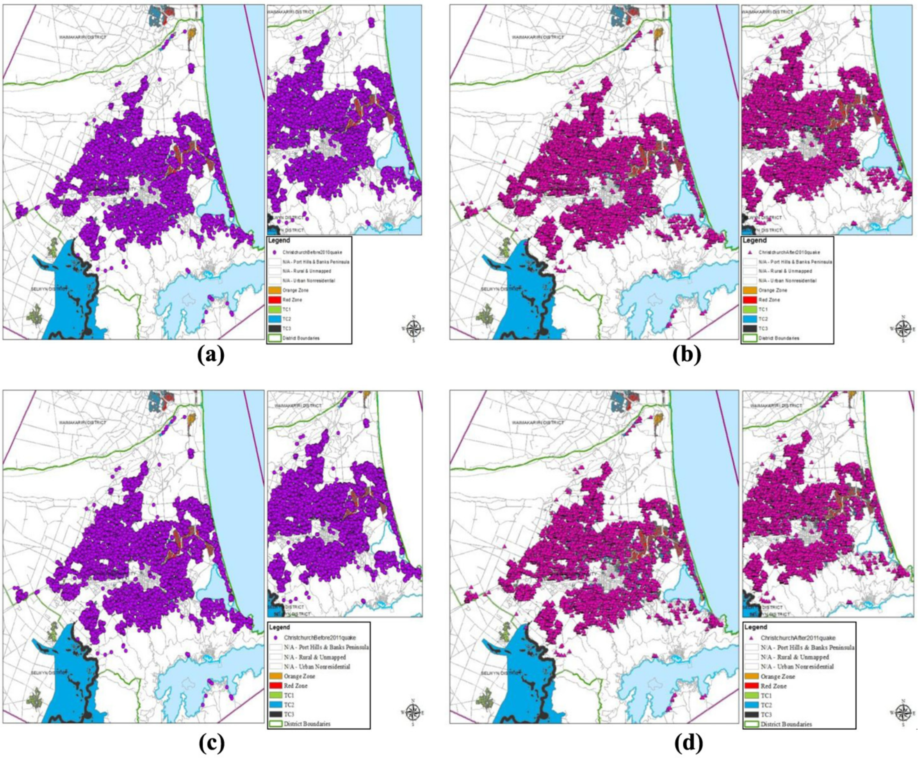

Figure 2. Location of Christchurch houses sold before and after the 9/4/10 and the 2/22/11 earthquakes

Notes: (a) Houses sold before the 9/4/10 quake; (b) houses sold after the 9/4/10 quake; (c) houses sold before the 2/22/11 quake; (d) houses sold after the 2/22/11quake

(1) *House characteristics* such as latitude, longitude, address, land and floor area, exterior and roof façade, type (residence, land, unit, townhouses and apartments), sale price, valuation, year constructed, listing and agreement dates, number of bedrooms, listing and sale prices (NZ$), time on the market (sell days), area/municipal district.

(2) *Land zones*, based on CERA's assessment of land and building damage and risk of liquefaction [TC1 through TC3, N/A – port hills and banks peninsula, N/A – rural and unmapped, N/A – urban non-residential, orange and red zones, etc.].

The original data set went through a series of transformations:

(1) determination of a narrower and more homogeneous urban fabric area of Christchurch (Figure 1);

(2) matching and confirming the house's geocoding and the districts used in the study to avoid mislabelling; and

(3) determination of a homogenous housing type for the analysis which included residences and excluded units, townhouses and apartments. Vacant land and red zones were also excluded from the final data set.

The use of the ValBiz sales data was instrumental in the updating of the missing information of the original data set including the year of construction and the exterior and roof façade materials. The updated data set was then integrated into a single file with all the districts which allowed the statistical analysis. The identification of the sales timing agreements as before or after the two earthquakes (4 September 2010 and 22 February 2011, respectively) and their overlay above the land zones (Figures 2 through 4).

Because of the house densities shown in Figure 2, the visual identification of the land zones underneath the houses cannot be easily made. The final data set included 9,946 house sales located in Christchurch. The sales agreements spanned from September of 2008 through June 2012.

Results

A first step in assessing the perception of risk associated with house sales after the two earthquakes (9/4/10 and the 2/22/11) was the determination of the average trends among selected house characteristics before and after the quakes for Christchurch (Figure A2 – Appendix 2).

On average, sale prices increased and sales of newer construction increased after both quakes. This result holds for the TC1 and TC2 areas after the second quake and for TC2 after the first quake. The comparison among the three land zones shows less consistency between TC1 and TC2 areas, with TC3 areas not showing any statistically significant difference when comparing the average sale prices before and after both quakes. When analysing the TC3 area average sale prices, those prices seem to be the highest compared to either TC1 or TC2; this lowers the possibility of a significant increase, especially after a quake in an area designated with a moderate to significant damage possibility after another quake. The absence of any statistical difference among average sale prices in TC3 areas is therefore an indication of less negative property price effect in these areas regardless of the negative media attention. The review of the average prices of the other structure characteristics' before and after a quake shows less consistency.

Figure A3 – Appendix 3 show the hotspot analysis of sale prices experienced in Christchurch before and after the earthquakes. Figure 3 results suggest the existence of clusters (hotspots) with similar sale prices northwest of the downtown area (shown in red dots with a 99 per cent confidence level) and in the south. The red dots suggest homogeneity of sale prices in certain areas in contrast to other areas where there seems to be lack of significant variability. The comparison of before and after the first quake (9/4/2010) trends does not show significant difference in the allocation of hotspots except for a small cluster southwest of the downtown which suggest some very similar sale prices in close proximity to the TC2 zone. The sale price trends before and after the second quake (2/22/2011) do not suggest major differences except for three small clusters, southwest, southeast and northeast, of the downtown.

This next section presents the results from the multiple regression models used to quantify the relationship between house sales price and their characteristics (Tables AI and AII – Appendix 4). Tables AI and AII provide the regression results of the Christchurch district overall and each of the three land zones within the district limits. Three of the variables have a consistently positive effect on sales prices across all models in both tables and regardless of the quakes: newer houses, houses with a larger number of bedrooms and houses with a larger land area. For example, in Columns 1 through 4, the results suggest that for every more-recent decade a structure is built, sale prices increase by 5.24 and 5.12 per cent (Columns 1 and 2) before the first and second quake, respectively, and 5.65 and 5.88 per cent (Columns 2 and 4) after the quakes, respectively. Looking at the construction year row in both Tables AI and AII, it is evident that the newer houses seem to be achieving the highest sales price effect in TC3 zones after both quakes, with an increase of 7.07 per cent (Column 6) and 7.38 per cent (Column 8) suggesting that people feel confident that newer houses in these areas are more resilient in the face of future quakes versus older ones.

The effect of both additional number of bedrooms and land area on sale price is as would be expected and therefore additional discussion is not provided. The effect of agreement year on sale prices is worthy of discussion, however. Columns 5 and 7 (TC1 zone) suggest that houses with fairly recent agreement years, but before either of the two quakes, transacted with lower prices by 4.81 and 3.49 per cent, respectively. In contrast, more recent sale agreements which took place after the quakes in TC1 experienced a sale price appreciation (by 4.77 and 5.86 per cent, Columns 6 and 8, respectively). This result may be caused by two possibilities which cannot be investigated further based on the available data:

- the need for housing after a quake has destroyed thousands of homes is significant and therefore the supply and demand balance leads to more agreements after a quake with higher prices and/or; and
- buyers are showing resilience and are willing to pay a premium for quality and surviving housing stock regardless of location in a TC1 and TC2 zones.

The exterior façade[2] material with a more constant positive effect on sales prices before and after both quakes is a mixture (of materials), and roughcast in the majority of zones. In contrast, the effect of concrete and wood façades in the TC1 zone (Columns 5 through 8) had a statistically significant negative effect before both earthquakes on sales prices, which was not sustained after the quakes even though the effect of this type of façade continued to be mainly negative in this area. In TC3 zones, however, the concrete façades continued to have a statistically significant negative effect on sales prices after the quakes.

The effect of roof façade material on sale prices is less consistent, with the only exception being tile, which has a negative effect in the overall data set and the TC2 zone. In the overall data set, a tile roof is associated with a 5.95 per cent decrease in the sale price before the first quake and a 4.56 per cent decrease after the first quake. This trend remains almost constant before and after the second quake (Columns 1 through 4). This effect is expected because tile roofs are heavier, causing more extensive damage than other material. In contrast, malthoid roofs which are lighter have a strong positive effect on sale prices on both the overall data and the TC2 zone, with the effect significantly magnifying after the second quake (23.9 per cent after the first quake and 33.3 per cent after the second quake, respectively, for the overall data, and 36.5 and 52.8 per cent, respectively, for the TC2 zone after the first and second quakes).

Conclusions

The overall data comparison regardless of land zone (TC1 through TC3) suggests that sale prices increased on average after both Canterbury earthquakes (9/4/2010 and the 2/22/2011). This trend is also experienced within TC1 and TC2 zones but not in TC3 zone, which did not show any statistically significant price differentiation when comparing the periods before and after both quakes. The lack of any significant difference in the average sale prices of houses before or after both quakes in the TC3 areas suggests that regardless of the negative media coverage of these zones, the sale prices did not experience major shifts; this is indicative of risk aversion among individuals purchasing houses in these zones. The hotspot analysis of sale prices provides evidence of concentrations across all three districts with limited differentiation between the two quakes.

The regression models provided a plethora of evidence regarding the perception of risk through the lens of sale price impact, while accounting for property characteristics. The models applied indicated significant similarities across all models. Newer houses achieved higher sale prices, both before and after both quakes, but the effect was even higher for the TC3 zones. This result shows buyer confidence in newer houses, which are built to conform with updated building codes and therefore decrease the perception of risk, especially in TC3 zones.

An interesting finding is that sale agreements after either of the two quakes are associated with a price appreciation for the overall data set and TC1 and TC2 zones; however, the TC3 zone experienced a sale price decrease after the second quake. This result suggests supply–demand pressures, the possibility of resiliency (sale price increase) or an increased presumption of risk if certain house characteristics (e.g. newer construction etc.) are not met (TC3 zones). Shifting the focus to façade material, mixture and roughcast have a positive effect on sale prices in the overall data set and in the TC1 and TC2 zones after both quakes but in some cases before the quakes too. Other material such as wood have a positive effect on sale prices, although the effect does not remain significant across all zones. Among the studied roof materials, only tile has a more consistent negative effect on sale prices for the overall data set and TC2[3]. The other type of material with a constant effect after the both quakes in the overall data and TC2 is malthoid; however, because of the lightness of the material in contrast to that of the tile, the effect is positive and expected.

In conclusion, the results indicate that with the recent earthquake experience, residents are demonstrating risk mitigation behaviours through an aversion to (paying lower prices for) TC3 zoned property that are regarded to be a higher risk for future liquefaction and flooding. However, the quality of the house can overcome the media stigma attached to the TC3 zones. This confirms the findings in the Bond (2015) study that there was a perception of risk towards damaged property and TC3 land in particular.

This research will be of interest to government agencies tasked with assessing compensation for affected property owners. For example, the EQC developed a *Diminution of Value Methodology for Increased Flooding Vulnerability* that formed the basis of a High Court declaratory judgement decision in December 2014 that cleared the way for EQC to start settling properties with increased flooding vulnerability. The EQC methodology was informed by the results of similar studies to this one, from around the world. Homeowners and rating valuers will also be interested in the results to understand how house prices have been affected by market perceptions towards earthquake damage, particularly in the worst-affected areas.

Notes

1. The statistical analysis focused on three land zones (TC1, TC2 and TC3).
2. Exterior and roof façade material are dummy variables and therefore their coefficient results are adjusted to reflect this in the text.
3. Note that for TC2 zoned land, pile foundations are suitable for houses that are built of lightweight materials (not masonry or brick veneer) and have timber floors instead of concrete floors, or enhanced (rib raft) slabs, indicating a preference for lighter materials to reduce the weight of the house/load on foundations.

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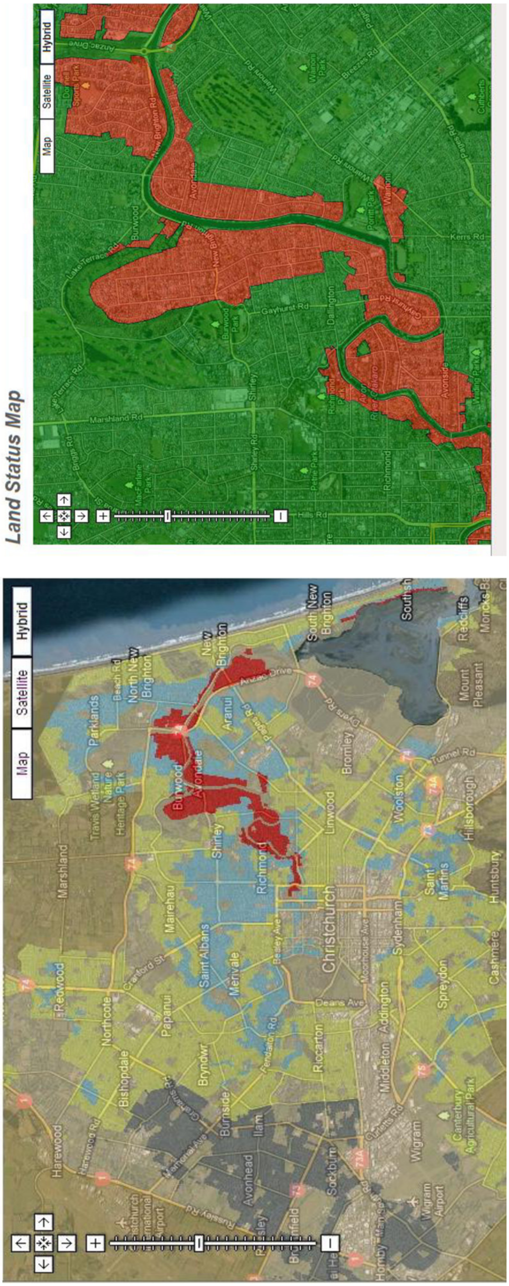
Appendix 1



Notes: Key: TC1 – grey; TC2 – yellow; TC3 – blue, red – The land that has been badly damaged and rebuilding it is unlikely
Source: Available at: http://cera.govt.nz/sites/cera.govt.nz/files/common/dbh-residential-foundation-technical-categories-20120323.pdf (https://creativecommons.org/licenses/by/3.0/nz/)

Figure A1.
Technical category map and red zone map

Appendix 2. Descriptive statistics

Agreement Before quake Sept. 4th 2010			
Variable	#observ.	Average	st. dev.
Valuation	4254	410,526	236,382
Sale_Price	4345	406,933	229,905
Const. Year	4213	1,963	27
#bedrooms	4345	3.18	1.14
Sell_Days	3937	44.55	58.74
Land area	3502	725.27	343.90

Agreement Before quake Feb. 22nd 2011			
Variable	#observ.	Average	st. dev.
Valuation	5,491	409,526	235,528
Sale_Price	5615	406,027	232,064
Const. Year	5438	1,963	27
#bedrooms	5615	3.19	1.11
Sell_Days	5112	46.57	57.80
Land area	4509	726.82	388.38

T-tests before vs. after quake Sept. 4th 2010	
Variable	t-test result
Valuation	1.046
Sale_Price	−2.47
Const. Year	−6.34
#bedrooms	−1.87
Sell_Days	−3.00
Land area	1.97

T-tests before vs. after quake Feb. 22nd 2011	
Variable	t-test result
Valuation	0.8793
Sale_Price	−3.68
Const. Year	−7.48
#bedrooms	−1.79
Sell_Days	−0.65
Land area	3.07

The differrence of means in variable(x) before vs. after quake Sept. 4th 2010 or Feb. 22nd 2011 is more than 0

Agreement After quake Sept. 4th 2010			
Variable	#observ.	Average	st. dev.
Valuation	5464	405,640	217,806
Sale_Price	5601	418,333	225,849
Const. Year	5421	1,966	27
#bedrooms	5601	3.22	1.02
Sell_Days	5286	48.85	78.70
Land area	4447	709.53	364.57

Agreement After quake Feb. 22nd 2011			
Variable	#observ.	Average	st. dev.
Valuation	4,227	405,510	213,303
Sale_Price	4331	422,849	221,555
Const. Year	4196	1,967	27
#bedrooms	4331	3.23	1.02
Sell_Days	4111	47.57	84.40
Land area	3440	702.90	307.11

Agreement Before quake Sept. 4th 2010 in TC1			
Variable	#observ.	Average	st. dev.
Valuation	725	379,477	142,442
Sale_Price	739	374,372	137,543
Const. Year	723	1,969	18
#bedrooms	739	3	1
Sell_Days	681	41.44	47.75

Agreement Before quake Feb. 22nd 2011 in TC1			
Variable	#observ.	Average	st. dev.
Valuation	944	375,145	139,335
Sale_Price	964	370,989	134,169
Const. Year	942	1,969	18
#bedrooms	964	3	1
Sell_Days	893	43.49	49.07

T-tests before vs. after quake Sept. 4th 2010 - TC1	
Variable	t-test result
Valuation	1.94
Sale_Price	−1.40
Const. Year	−1.63
#bedrooms	0.10
Sell_Days	−0.50

T-tests before vs. after quake Feb. 22nd 2011 - TC1	
Variable	t-test result
Valuation	1.11
Sale_Price	−2.99
Const. Year	−2.47
#bedrooms	−0.37
Sell_Days	1.12

Agreement After quake Sept. 4th 2010 in TC1			
Variable	#observ.	Average	st. dev.
Valuation	1160	366,894	127,869
Sale_Price	1190	382,965	121,143
Const. Year	1159	1,971	20
#bedrooms	1190	3	1
Sell_Days	1139	42.61	50.22

Agreement After quake Feb. 22nd 2011 in TC1			
Variable	#observ.	Average	st. dev.
Valuation	941	368,312	127,917
Sale_Price	965	388,347	120,355
Const. Year	940	1,971	20
#bedrooms	965	3	1
Sell_Days	927	40.90	49.51

Agreement Before quake Sept. 4th 2010 in TC2			
Variable	#observ.	Average	st. dev.
Valuation	2390	389,799	194,981
Sale_Price	2446	387,172	190,542
Const. Year	2370	1,961	29
#bedrooms	2446	3	1
Sell_Days	2226	44.49	63.74

Agreement Before quake Feb. 22nd 2011 in TC2			
Variable	#observ.	Average	st. dev.
Valuation	3121	387,494	186,784
Sale_Price	3199	386,253	190,890
Const. Year	3094	1,961	29
#bedrooms	3199	3	1
Sell_Days	2925	46.53	61.11

T-tests before vs. after quake Sept. 4th 2010 - TC2	
Variable	t-test result
Valuation	−1.01
Sale_Price	−4.88
Const. Year	−5.57
#bedrooms	−1.45
Sell_Days	−2.04

T-tests before vs. after quake Feb. 22nd 2011 - TC2	
Variable	t-test result
Valuation	−2.23
Sale_Price	−6.48
Const. Year	−6.56
#bedrooms	−1.62
Sell_Days	−0.43

Agreement After quake Sept. 4th 2010 in TC2			
Variable	#observ.	Average	st. dev.
Valuation	3428	395,078	199,835
Sale_Price	3515	412,978	214,724
Const. Year	3395	1,965	29
#bedrooms	3515	3	1
Sell_Days	3315	48.64	87.74

Agreement After quake Feb. 22nd 2011 in TC2			
Variable	#observ.	Average	st. dev.
Valuation	2697	399,176	209,801
Sale_Price	2762	421,079	219,824
Const. Year	2671	1,966	29
#bedrooms	2762	3	1
Sell_Days	2616	47.47	95.11

Agreement Before quake Sept. 4th 2010 in TC3			
Variable	#observ.	Average	st. dev.
Valuation	833	428,555	339,181
Sale_Price	851	429,235	338,771
Const. Year	825	1,959	29
#bedrooms	851	3	1
Sell_Days	758	44.15	48.43

Agreement Before quake Feb. 22nd 2011 in TC3			
Variable	#observ.	Average	st. dev.
Valuation	1040	431,698	348,555
Sale_Price	1062	430,686	347,951
Const. Year	1031	1,959	29
#bedrooms	1062	3	1
Sell_Days	950	46.52	51.80

T-tests before vs. after quake Sept. 4th 2010 - TC3	
Variable	t-test result
Valuation	−0.55
Sale_Price	−0.41
Const. Year	−0.33
#bedrooms	−1.74
Sell_Days	−3.07

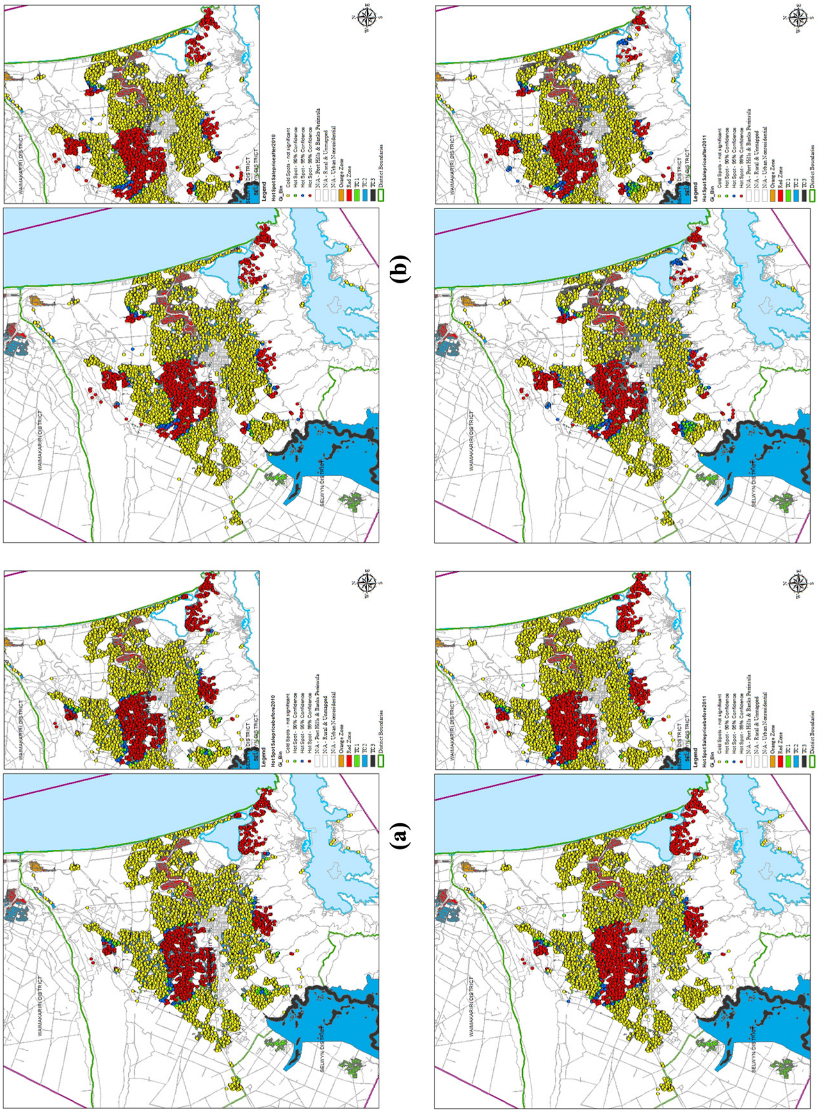
T-tests before vs. after quake Feb. 22nd 2011 - TC3	
Variable	t-test result
Valuation	−0.20
Sale_Price	−0.31
Const. Year	−0.22
#bedrooms	−1.30
Sell_Days	−1.76

Agreement After quake Sept. 4th 2010 in TC3			
Variable	#observ.	Average	st. dev.
Valuation	623	438,187	319,135
Sale_Price	637	436,501	336,497
Const. Year	622	1,959	31
#bedrooms	637	3	1
Sell_Days	590	53.98	65.00

Agreement After quake Feb. 22nd 2011 in TC3			
Variable	#observ.	Average	st. dev.
Valuation	416	435,123	281,416
Sale_Price	426	436,483	311,048
Const. Year	416	1,959	31
#bedrooms	426	3	1
Sell_Days	398	53.06	66.17

Figure A2.
Christchurch descriptive statistics

Appendix 3. Cluster, hotspot analysis



Notes: (a) Houses sold before the 9/4/10 quake; (b) houses sold after the 9/4/10 quake; (c) houses sold before the 2/22/11 quake; (d) houses sold after the 2/22/11quake

Figure A3.
Christchurch sale price hotspots before and after the 9/4/10 and the 2/22/11 earthquakes

Appendix 4. Hedonic modelling

	Overall data				Area designation: TC1			
	(1) Before 9/4/10 quake	(2) After 9/4/10 quake	(3) Before 2/22/11 quake	(4) After 2/22/11 quake	(5) Before 9/4/10 quake	(6) After 9/4/10 quake	(7) Before 2/22/11 quake	(8) After 2/22/11 quake
Const.Year	0.00524*** (16.52)	0.00565*** (21.49)	0.00512*** (18.20)	0.00588*** (21.06)	0.00692*** (9.01)	0.00587*** (14.03)	0.00678*** (10.04)	0.00582*** (13.12)
Bedrooms	0.150*** (15.31)	0.145*** (18.15)	0.151*** (17.58)	0.142*** (16.22)	0.123*** (7.01)	0.122*** (12.38)	0.125*** (8.74)	0.119*** (10.92)
Agr.Year	−0.0154 (−1.43)	0.0376*** (5.50)	−0.0147 (−1.71)	0.0271** (2.59)	−0.0481* (−2.29)	0.0477*** (4.85)	−0.0349* (−2.20)	0.0586*** (3.96)
Sell_days	−0.000193 (−1.55)	−0.000160 (−1.20)	−0.000159 (−1.34)	−0.000187 (−1.22)	−0.000320 (−1.46)	−0.000238 (−1.45)	−0.000297 (−1.67)	−0.000198 (−1.00)
Land_area	0.000308*** (4.97)	0.000237*** (4.21)	0.000248*** (4.06)	0.000290*** (6.21)	0.000351** (3.15)	0.000405*** (8.62)	0.000334*** (3.64)	0.000425*** (8.21)
Exterior façade material								
Brick	0.0847 (1.65)	0.0294 (0.64)	0.0858 (1.72)	0.00823 (0.16)	0.0931 (1.81)	0.0625 (1.23)		
Concrete	−0.00354 (−0.07)	−0.0452 (−0.98)	−0.00498 (−0.10)	−0.0592 (−1.16)	−0.0467* (−1.97)	0.0258 (0.51)	−0.0519* (−2.55)	−0.00282 (−0.06)
Fibrolite	−0.0555 (−0.93)	−0.0821 (−1.55)	−0.0665 (−1.17)	−0.0746 (−1.28)	−0.322*** (−4.41)	−0.153* (−2.43)	−0.275*** (−4.31)	−0.213*** (−3.46)
Mixture	0.176** (3.15)	0.155** (3.10)	0.179*** (3.30)	0.139* (2.49)	0.0966** (2.88)	0.145* (2.23)	0.0720* (2.41)	0.131 (1.93)
Roughcast	0.186*** (3.51)	0.183*** (3.81)	0.183*** (3.55)	0.182*** (3.46)	0.0932 (1.73)	0.167** (2.93)	0.111* (2.49)	0.116* (2.04)
Stone	0.133 (1.76)	0.155* (2.15)	0.149* (2.07)	0.133 (1.66)	0.0951 (0.62)	0.148 (1.43)	0.0960 (0.63)	0.121 (1.16)
Wood	0.192*** (3.62)	0.152** (3.14)	0.185*** (3.57)	0.146** (2.77)	−0.101** (−2.80)	−0.0496 (−0.91)	−0.0998*** (−3.38)	−0.0902 (−1.62)
Roof façade material								
Fibrolite	−0.126* (−2.21)	−0.166* (−2.57)	−0.107 (−1.93)	−0.205** (−2.95)	0 –	0.000334 (0.02)	0.0709** (2.72)	0
Malthoid	0.136 (1.60)	0.239* (2.25)	0.0857 (1.03)	0.333** (2.97)	0 –	0.0519 (0.89)	0 –	0.0576 (0.86)
Mixture	0.0367 (0.42)	−0.0625 (−0.93)	0.0361 (0.49)	−0.0825 (−1.10)	0.0890* (2.21)	0.0420 (0.79)	0.202* (2.18)	0.0196 (0.34)
Tile	−0.0595*** (−5.57)	−0.0456*** (−4.94)	−0.0600*** (−6.21)	−0.0401*** (−3.90)	−0.00893 (−0.41)	−0.0130 (−0.92)	−0.0246 (−1.34)	0.00333 (0.21)
_cons	32.63 (1.52)	−74.61*** (−5.43)	31.66 (1.83)	−53.97* (−2.56)	95.16* (2.25)	−95.46*** (−4.83)	68.95* (2.15)	−117.2*** (−3.93)
N	3174	4177	4100	3251	517	880	684	713
R^2	0.413	0.433	0.404	0.449	0.483	0.543	0.502	0.534
vif	4.95	3.95	4.44	4.15	1.17	3.26	1.16	3.23

Notes: *t*-statistics in parentheses; * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$

Table AI. Assessment of the effect of the two major earthquakes on the sale prices of the Christchurch area (overall and TC1)

Table AII. Assessment of the effect of the two major earthquakes on the sale prices of the Christchurch area (TC2 and TC3)

	Area designation: TC2				Area designation: TC3			
	(1) Before 9/4/10 quake	(2) After 9/4/10 quake	(3) Before 2/22/11 quake	(4) After 2/22/11 quake	(5) Before 9/4/10 quake	(6) After 9/4/10 quake	(7) Before 2/22/11 quake	(8) After 2/22/11 quake
Const.Year	0.00578*** (16.39)	0.00593*** (19.21)	0.00556*** (18.15)	0.00616*** (17.95)	0.00432*** (5.11)	0.00707*** (8.06)	0.00472*** (6.34)	0.00738*** (6.72)
Bedrooms	0.123*** (11.56)	0.130*** (12.93)	0.126*** (13.51)	0.127*** (11.38)	0.173*** (6.62)	0.178*** (6.20)	0.157*** (6.95)	0.217*** (6.09)
Agr.Year	−0.0142 (−1.11)	0.0467*** (5.53)	−0.0133 (−1.36)	0.0399** (3.07)	−0.00293 (−0.10)	−0.0231 (−0.97)	0.00423 (0.18)	−0.108* (−2.43)
Sell_days	−0.000234 (−1.72)	−0.000290 (−1.57)	−0.000257* (−2.17)	−0.000259 (−1.24)	−0.000265 (−0.65)	0.000308 (0.70)	0.0000825 (0.19)	0.0000389 (0.08)
Land_area	0.000466*** (11.16)	0.000334*** (5.16)	0.000476*** (14.10)	0.000303*** (4.45)	0.000644*** (6.87)	0.000726*** (8.25)	0.000685*** (8.72)	0.000632*** (4.19)
Exterior façade material								
Brick	0.115 (1.90)	0.0867 (1.35)	0.124* (2.49)	0.0584 (0.75)	0.0939 (0.98)	−0.436* (−2.53)	−0.00700 (−0.07)	−0.477 (−1.94)
Concrete	0.00479 (0.08)	0.00267 (0.04)	0.0181 (0.36)	−0.0240 (−0.31)	−0.0134 (−0.14)	−0.477** (−2.80)	−0.108 (−1.09)	−0.487* (−1.98)
Fibrolite	−0.0540 (−0.76)	−0.00463 (−0.06)	−0.0586 (−0.98)	0.0100 (0.12)	−0.118 (−1.13)	−0.475* (−2.58)	−0.208 (−1.88)	−0.473 (−1.86)
Mixture	0.174* (2.57)	0.214** (3.17)	0.181** (3.27)	0.203* (2.47)	0.322** (2.70)	−0.142 (−0.74)	0.279* (2.27)	−0.245 (−0.92)
Roughcast	0.193** (3.08)	0.228*** (3.54)	0.184*** (3.56)	0.228** (2.92)	0.218* (2.11)	−0.0536 (−0.31)	0.153 (1.44)	−0.0724 (−0.29)
Stone	0.0643 (0.70)	0.141 (1.56)	0.0659 (0.86)	0.137 (1.28)	0.331 (1.64)	−0.0611 (−0.26)	0.212 (1.38)	0.209 (0.62)
Wood	0.225*** (3.59)	0.210** (3.28)	0.226*** (4.38)	0.194* (2.46)	0.237* (2.40)	−0.0354 (−0.21)	0.165 (1.61)	−0.0158 (−0.06)
Roof façade material								
Fibrolite	−0.156* (−2.23)	−0.0965 (−1.32)	−0.117 (−1.58)	−0.119 (−1.65)	−0.0532 (−0.50)	−0.594*** (−5.15)	−0.0956 (−0.92)	−0.578*** (−5.14)
Malthoid	0.0869 (0.76)	0.365* (2.27)	0.00672 (0.06)	0.528*** (4.09)	0.246*** (3.39)	0.00867 (0.04)	−0.0194 (−0.12)	−0.00400 (−0.02)
Mixture	−0.0356 (−0.39)	−0.0475 (−0.43)	−0.0414 (−0.45)	−0.0550 (−0.51)	0.258 (0.83)	−0.261 (−1.92)	0.00420 (0.02)	−0.400*** (−6.07)
Tile	−0.0647*** (−4.99)	−0.0547*** (−4.95)	−0.0659*** (−5.92)	−0.0511*** (−4.05)	−0.0568 (−1.95)	−0.0244 (−0.67)	−0.0503 (−1.95)	−0.0337 (−0.72)
_cons	29.24 (1.14)	−93.53*** (−5.49)	27.81 (1.42)	−80.18** (−3.06)	9.094 (0.16)	44.58 (0.93)	−5.967 (−0.13)	214.9* (2.40)
N	1811	2631	2366	2076	616	478	764	330
R^2	0.452	0.454	0.450	0.461	0.426	0.491	0.455	0.475
vif	4.39	4.38	4.11	4.76	5.25	5.00	5.11	5.17

Notes: *t* statistics in parentheses; $^{*}p < 0.05$, $^{**}p < 0.01$ and $^{***}p < 0.001$