Earthquake Risk and Housing Prices: A Hedonic Analysis of the Victoria Real Estate Market

By

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We accept this extended essay as conforming
to the required standard

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Abstract

Within the city of Victoria, there is high variation in relative earthquake risk over short distances. The BC Geological Survey published an earthquake risk map that identifies relatively more dangerous microregions within the city. I construct a hedonic pricing model to analyze the extent of negative price discounting. I also estimate the implications of the earthquake map publication using difference-in-differences estimation. In results that are consistent with prior findings, I establish that earthquake risk is capitalized into home values in Victoria. However, I find that there is a non-monotonic relationship between risk and price. Houses are discounted for risk, but the magnitude of the risk capitalization does not increase with relative risk level. In addition, I find that the relative earthquake hazard map has no effect on home values.

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1. Introduction

In this paper I use a hedonic price model to identify the extent to which the risk of earthquake damage is capitalized into home values in Victoria, British Columbia. Other things equal, a house should be less expensive in a relatively riskier area if the house price reflects full information. I focus specifically on earthquake risks described by a composite measure provided by the BC Geological Survey because this is the primary information on earthquake risk available to homebuyers in Victoria. Only with the aid of this risk map (or an expensive geotechnical consultation) would a non-geologist homebuyer be equipped to distinguish a risky area from a relatively safer one. I treat the year 2000 publication of this composite earthquake hazard map as an exogenous change in information. This exogenous change provides an ideal basis for a natural experiment on whether earthquake risk is capitalized into house values.

In the past calendar year, Earthquakes Canada has recorded over 1200 measurable earthquakes in Southwestern British Columbia. Despite Southern Vancouver Island being a relatively unsafe area to live in with respect to global relative earthquake risk, it has not experienced any devastating earthquakes. However, residents of the "Pacific Rim of Fire" understand that experiencing an earthquake is unavoidable. Whether that experience entails harmless vibrations or widespread loss remains to be seen. But because the "big one" could occur at any time, it is important for residents to properly insure against seismic risk.

There several ways people can insure themselves against earthquake loss. Homeowners can self-select into relatively safer areas, purchase earthquake-comprehensive home insurance, perform seismic retrofitting, or undertake any combination of the three. These options require that people be made aware of the hazard levels associated with specific geographical microregions. Without this information, the average homebuyer could not recognize the relatively safety differences between homes in different areas. Surprisingly, there is much variation in relative earthquake risk within relatively small geographical areas (BC Geological Survey, 2000). Within a few city blocks, earthquake hazard rating can fluctuate from low to moderate, moderate to high, and then from high back to low, again.

The BC Geological Survey published a composite earthquake hazard map for the Greater Victoria area of British Columbia in 2000. The map identifies areas where earthquake hazard may be higher due to unstable slope, potential ground amplification, and potential soil liquefaction. Before this map was published online, detailed regional-specific earthquake hazard information was not widely available. Without the detailed information the map provides, people would not have been able to accurately base their house buying decisions on relative earthquake risks.

Informational conditions in Victoria make it an ideal location for a natural experiment. The publication of a detailed earthquake risk map may have widespread implications—especially to homeowners and prospective home-buyers. A press release in the Times Colonist, a southern Vancouver Island newspaper, accompanied the map publication. This method of information transfer is arguably unemotional. Newspaper publications do not immediately affect people's liquidity or safety, so it is possible to separate educational effects on house price from emotional ones.

Whether people respond to new information in expected ways may be of use to the government if it wishes to facilitate the flow of information. This information may to help markets function smoothly, especially if it has implications for public health and safety. Salience refers to the prominence in perception of relevant information. It may take years for people to fully understand and act upon informational changes (Chetty, Friedman, & Saez, 2012). The publication of the earthquake risk map is an ideal benchmark from which to measure how people respond to information. The discussion about salience continues in section 5.

Based on the available literature, this is the first time earthquake risk capitalization has been measured for the Greater Victoria area. My objective is twofold:

1. I attempt to replicate the results of previous natural experiments involving earthquake risk capitalization using unique, multi-level earthquake hazard ratings.
2. I use an exogenous change in information about relative earthquake risks to measure the market response of homebuyers using a difference-in-differences model specification.

The results presented here are consistent with prior findings. I find that relative earthquake risk is capitalized into home values and that the extent of capitalization is dependent on risk level. Counter-intuitively, there is a non-monotonic relationship between risk and price. Houses are discounted for risk, but the magnitude of the risk capitalization does not increase with relative risk level. I conclude that the publication of the earthquake relative hazard map had no statistically significant effect on house prices.

These findings are consistent with three possible outcomes: People were not aware of risk zones before or after the map was published; people were aware of risk zones before and after the map was published; the differences in risk zones are negligible. The implications of these possible outcomes will be discussed further in section 5.

The paper will proceed as follows; I first outline the hedonic methodology used in my analysis, then I present the data used in my analysis. Next, I compare the results from a base case ordinary least squares regression with the results from a difference-in-differences approach that exploits the natural experiment provided by the year 2000 publication of the BC Geological Survey map. I then discuss the implications of the results and propose several directions for future research.

2. Existing Literature

Property value information is used to construct hedonic pricing models that estimate the relative damages inflicted by environmental disameneties such as air pollution and noise pollution. Freeman (1979) examined several criticisms of the hedonic pricing technique. For example, one common criticism is that the model is limited to measuring the marginal implicit prices for amenities at home, only. Any benefits accrued away from one's place of residence are not measured. Another drawback is the inherent difficulty of interpreting coefficients; marginal implicit prices can only be interpreted as marginal willingness to pay if the housing market is in equilibrium. Acknowledging the limitations of the hedonic pricing method, Freeman concluded that this method is not perfect, but is useful for pricing nonmarketable amenities.

Hedonic price models can be useful tools for revealing the implicit prices of risk and for identifying changes in consumer behaviour. In Los Angeles County and the bay area of San Francisco, state legislation stipulating the identification of houses in relatively more risky areas caused to people self-insure by buying homes in relatively safer areas. Relative risk information was divulged to homeowners directly and to homebuyers through an addendum to the purchase contract. On average, houses in riskier areas of Los Angeles County and Bay Area Counties were discounted by approximately 5.6% and 3.3%, respectively (Brookshire, Thayer, Tschirhart, & Schulze, 1985).

Similarly, nearby earthquake activity led to price discounting in Japan, suggesting that perceived risk influences home values (Naoi, Seko, & Sumita, 2009). I replicate these studies in Greater Victoria by analyzing changes in house prices across relative risk zones and after relevant hazard information is made public.

3. Data

I construct a unique data set from several sources. It is designed to accommodate hypothesis tests analyzing effects of relative earthquake risk on house price. The observations are limited to single-family dwellings from a selection of neighbourhoods in Greater Victoria and Oak Bay. I do not study the effects of risk on multiple-family dwellings, strata lots, or commercial properties. I select only single-family dwellings because construction and safety regulations are constant across this group. Including other use types may introduce systematic bias from differences in building codes.

Using data from the Landcor Data Corporation, I obtain a comprehensive sample of house and neighbourhood characteristics. Single-family dwellings that sold between

January 1997 and December 2003 in James Bay, Fairfield, Rocklands, Ross Bay, Foul Bay, Jubilee, Rock Bay, Haultain, Smith's Hill Reservoir, Hillside, Oak Bay South, Oak Bay Waterfront, and Gonzales Bay are included.

Qualitative house characteristics provided by Landcor include sale price, sale date, number of bedrooms, number of bathrooms, and neighbourhood. Repeat sales data are not included in my sample because only the most recent house sale information is available in the Landcor database to which I had access. Nominal house prices are adjusted to 2002 dollars[1] using the Canada-wide, all-items CPI obtained from Statistics Canada. The housing data set is truncated to exclude houses with sale values of zero dollars. Zero-dollar sale values denote rejected offers. The final data set includes 1491 observations on houses that traded between the years 1997 and 2003.

A summary of differentiable variables and indicator variables is presented in Table I. The mean adjusted sale price is $292,918.90 with a standard deviation of $175,643.78. The price data are quite spread out and positively skewed[2]. This is unsurprising given that there is a lower bound on sales price, but no upper bound. Both the mean and the median house age is 72. This number is unsurprising; many homes in James Bay, Fairfield, and Gonzales Bay—among other Victoria neighbourhoods—are character homes.

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[1] Note that I use the Canada-wide all-items CPI to adjust nominal sale prices.
[2] Since mean>median (median=$256,559.22)

TABLE I: SUMMARY STATISTICS

(1491 OBSERVATIONS)

DIFFERENTIABLE VARIABLES

	Mean	**S.D.**
Price[3]	292,918.89	175,643.78
Bathrooms	2	1.01
Bedrooms	3	1.11
Age of House	72	25.77
House Size (ft^2)	1898	843.69
Lot Size (ft^2)	6958	4,139.18

INDICATOR VARIABLES
(NUMBER OF HOUSES)

Fairfield	218	Registered Basement Suite	248
Foul Bay	107	Sale year 1997	224
Gonzales Bay	132	Sale year 1998	219
Haultain	78	Sale year 1999	213
Hillside	96	Sale year 2000	181
James Bay	63	Sale year 2001	184
Jubilee	167	Sale year 2002	215
Oaklands	91	Sale year 2003	255
Oak Bay South	292	Risk zone 1	673
Oak Bay Waterfront	23	Risk zone 2	214
Rock Bay	17	Risk zone 3	604
Smith's Hill Reservoir	144	Sale after map	713
Rockland	63	Sale after map	778

[3] Price is the left-hand-side variable of interest. It has been adjusted by the all-items, Canada-wide CPI.

The bottom portion of Table 1 lists right-hand-side indicator variables along with corresponding numbers of houses. Oak Bay South is the largest neighbourhood, both geographically and in terms of number of houses included. Other neighbourhoods include relatively few observations. Rock Bay contains very few single-family dwellings because it is predominantly zoned for commercial or industrial use. Oak Bay Waterfront encompasses a large geographical area, but has few single family dwellings. Rockland is simply a small neighbourhood relative to the others.

Houses in risk zones 1 and 3 dominate the sample, with 673 and 604 homes in each category. The number of house sales is fairly even across each sale year, and therefore relatively even when partitioned into categories indicating pre and post map publication.

I obtain geospatial vector data from the BC Geological Survey. This data set is available online, publicly and free-of-charge. It was published on May 4, 2000 both online and on the front page of the Times Colonist, a local newspaper.

Spatial data are geographically positioned. In the BC Geological Survey data, borehole samples from throughout Greater Victoria were used to identify the types of geological conditions that affect relative earthquake risk. The resulting information is contained in a shapefile, a format unique to geographical information system (GIS) software platforms.

Relative risk levels defined by the BC Geological survey are composed of an aggregate measure of relative soil liquefaction, relative ground amplification, and relative slope hazard. Soil liquefaction is the soil's tendency to behave like a liquid when shaken.

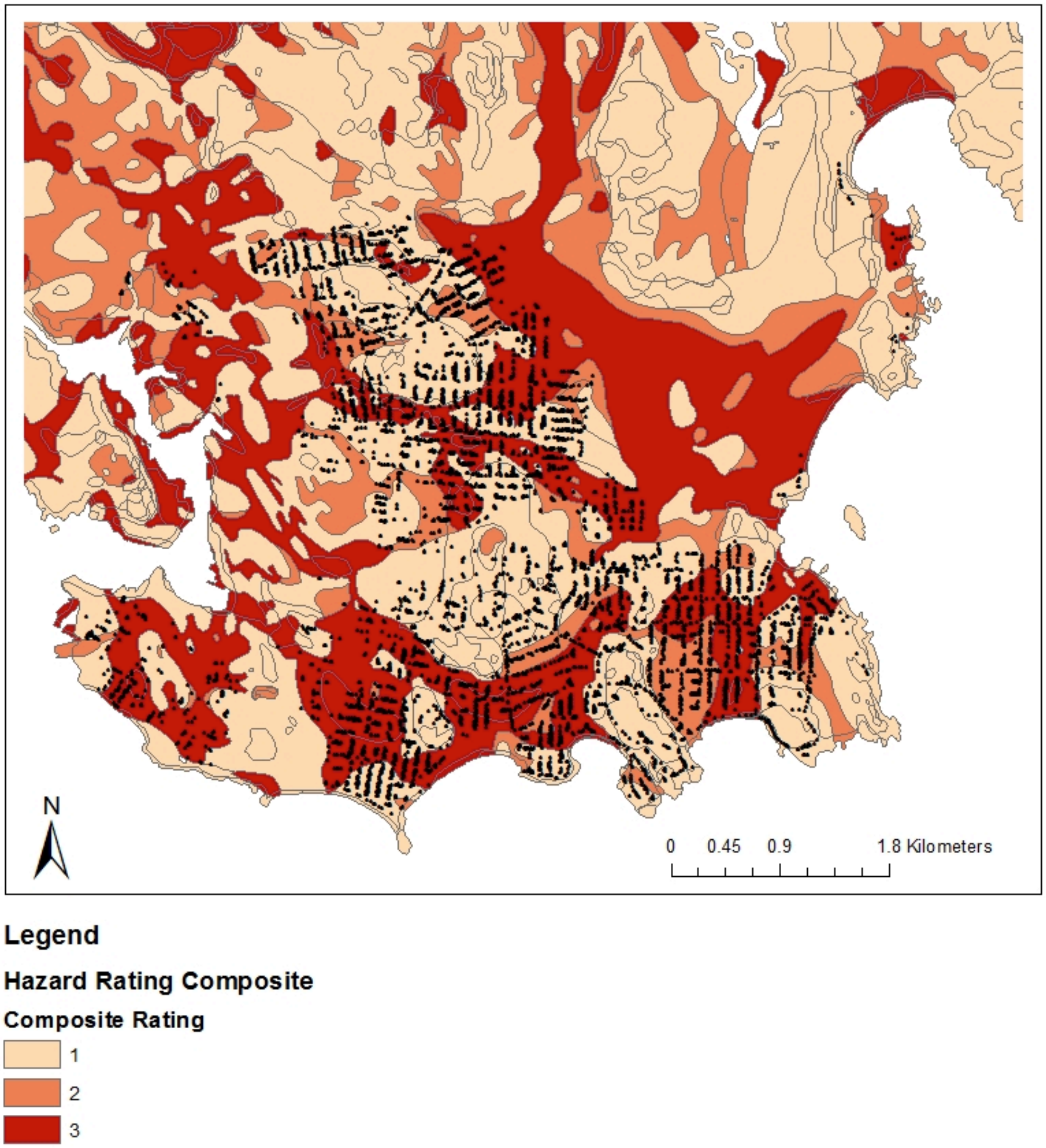
This component measures the potential for objects, including buildings, to sink into the ground in the event of an earthquake. A foundation that settles only a few centimeters below its original construction level may ruin the structural integrity of a building and render it uninhabitable (Juang, Yuan, Li, Yang, & Christopher, 2005). Measures of ground amplification refer the potential for vertical and lateral ground movement during an earthquake. Subterranean substances like clay may amplify ground movement, increasing the risk of foundational fissures (Westad, 2000). Slope hazard is a familiar and easily observable contributor to earthquake risk. Structures built on slopes, all else equal, are more dangerous than houses build on level surfaces. Slope grade and relative risk have a positive correlation (Westad, 2000).

The BC Geological survey ranks relative earthquake hazard risk on a scale of 1 to 6, from lowest risk to highest. These ordinal risk levels represent composite measures of the three relative risk categories discussed, above. Included in my sample are zones 1, 3, 5 and 6. I redefine zone 3 as zone 2, and zones 5 and 6 as zone 3. Henceforth, I refer to the newly redefined risk zones 1, 2, and 3.

To merge the Landcor housing data set with the geospatial data requires the use of ArcGIS, a GIS software suite. I constructed a spatial locator tool to project the house addresses onto the earthquake hazard map. A road network file provided spatial reference to the house addresses. Longitude and latitude coordinates for each address are generated based on information provided in the BC Roads Atlas. The road network file is projected in Universal Transverse Mercator (UTM) Zone 10, the zone that corresponds to Victoria's global positioning. A bilinear locator is utilized to project addresses onto the correct sides of the road (as opposed to directly in the middle of the road). A bilinear locator is essential for increasing the accuracy of risk zone labels.

Figure I displays the distribution of sample observations across Victoria and Oak Bay. Clustering is due to both neighbourhood boundary cutoffs and the distribution of single-family dwellings throughout the city. The emergent grid of observations reveals the city's roadways. Visual inspection reveals that risk zones do not seem to systematically coincide with roadways, along which neighbourhood boundaries are defined.

FIGURE I: COMPOSITE RELATIVE EARTHQUAKE RISK RATING[4]
HOUSE SALES 1997-2003 (1491 OBSERVATIONS)



[4] This map has been adapted from the Composite Relative Earthquake Hazard Map of Greater Victoria published publicly by the BC Geological Survey in 2000. Each point on the map represents one observation. Composite hazard ratings identify areas where hazard may be increased due to unstable slope, relative ground amplification, and relative soil liquefaction. Homes from downtown Victoria have not been included because there are no single-family dwellings located there. Only sales of greater than zero dollars in the neighbourhoods of James Bay, Fairfield, Rocklands, Ross Bay, Foul Bay, Jubilee, Rock Bay, Haultain, Smith's Hill Reservoir, Hillside, Oak Bay South, Oak Bay Waterfront, and Gonzales Bay are included.

3. Empirical Model

Hedonic price models are used to estimate the marginal willingness to pay for individual characteristics of a composite good. Hedonic valuation of real estate is based on the intuition that the value of a house is derived from constituent characteristics of the house, including but not limited to bedrooms, bathrooms, and neighbourhood amenities. House price is regressed on housing characteristics and neighbourhood characteristics, and the coefficients on regressors can be interpreted as contributions to a home's sales price (Sirmans, 2005). Conventionally, the semi-logarithmic form is estimated to allow changes in willingness to pay to be proportional to house price:

$$\ln(price_{ijt}) = \alpha + X_{it}\gamma + N_i\phi + Z_t\delta + risk_{ij}\beta + u_{ijt} \quad (1)$$

where $price_{ijt}$ indicates the sales price of house i in risk zone j in year t, adjusted by the CPI. Vector X_{it} includes house-specific characteristics, and N_i is a vector of neighbourhood indicator variables. A time trend is denoted by vector Z_t, which includes year-of-sale dummies. Ordinal relative hazard ratings are included in vector $risk_{ij}$. Coefficient vector β measures the change in willingness to pay (in dollars) for a constant-quality house in risk zone j compared with risk zone 1.

In addition to estimating the model given by Equation 1 above, I estimate the following difference-in-differences specification to measure changes in willingness to pay for homes with the introduction of new information about relative earthquake risk that occurred when BC Geological Survey published the earthquake risk map in 2000:

$$\ln(price_{ijt}) = \alpha + X_{it}\gamma + N_j\phi + Z_t\delta + risk_{ij}\beta + post_t\eta + post_t * risk_{ij}\theta + u_{ijt} \quad (2)$$

where $post_t$ takes on the value of 1 if the house sold after the publication of the earthquake relative hazard composite map and 0 if otherwise. Coefficient vector θ measures the change in relative willingness to pay (in dollars) for a constant-quality house in risk zone j going from before the earthquake map was published to after.

The differences-in-differences estimator measures the average percentage change in price of homes in the treatment group, minus the average percentage change in price of homes in the control group (Stock & Watson, 2011). In this case, it measures the average change in home value caused by the publication of the risk map.

The coefficients of (1) and (2) (when multiplied by 100) can be interpreted as marginal implied price changes, in percentage form. Coefficients β, η, and θ are approximations of percentage marginal willingness to pay since they are paired with non-differentiable indicator variables. I transform these coefficients to determine the exact percentage change in $price_{ijt}$ as $risk_j$, $post_t$, and $post_t * risk_{ij}$ switch from 0 to 1. For example:

$$\exp[\hat{\beta} - \tfrac{1}{2}(se(\hat{\beta}))^2] \quad (3)$$

yields the exact percentage impact on $price_{ijt}$ as $risk_{ij}$ switches from 0 to 1 (Kennedy, 1981).

For both of the above models, negative coefficients on the two relative risk indicator variables would indicate that earthquake risk is capitalized into home values in the expected way. All else equal, a house in a relatively more dangerous location should display evidence of greater price discounting.

4. Estimation Results and Robustness Checks

A. Main Results

Estimates of equation (1) are given in Table II column 1. Bedrooms and house age are not statistically significant. Bathrooms, house size, and lot size have positive coefficients and are statistically significant. Bedrooms, bathrooms, and house size are most often in the literature positively correlated with house sales price and statistically significant. House age is most often negatively correlated with sales price[5] (Sirmans, 2005).

The mean house age in this sample is 72. Many old homes in Victoria are designated heritage buildings or may be eligible for heritage designation. Victoria Heritage Foundation's House Grants Committee subsidize up to 30% of heritage home improvement project costs under certain conditions[6]. This potential subsidy may provide a heritage or heritage-potential premium. New houses require less upkeep, so they may also command a convenience or cost-savings premium. These opposing outcomes likely offset each other and lead to the statistical insignificance of house age[7].

Residential homes built before the 1990's often included many small bedrooms.

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[5] Sirmans *et al*. (2005) synthesize nearly 125 articles from various journals to identify variables consistently significant in explaining housing price.
[6] See Criteria for Heritage Designation at http://www.victoria.ca/EN/main/departments/planning-development/community-planning/heritage/criteria.html for more details.
[7] Including age^2 as an additional regressor in equations (1) and (2) may improve the model specification.

The current trend favouring open-concept living spaces may be counterbalancing the benefits of an additional bedroom, on the margin. Because Victoria is a retirement destination, elderly people may prefer space to additional bedrooms. With house size held constant, people may prefer fewer large bedrooms to many small bedrooms.

As expected, risk is negatively correlated with sales price. Coefficients on the two risk dummies indicate the percentage decreases in sale price as risk increases from zone 1 to zone 2 and from zone 1 to zone 3, respectively. An increase in risk from zone 1 to zone 2 is associated with a 5.3 percent decrease in house sales price, which is equivalent to a $15,524.70 decrease at the sample mean sales price. An increase in risk from zone 1 to zone 3 is associated with a 4.8 percent decrease in sales price. This is equivalent to a $14,060.11 price decrease at the mean.

Houses in relatively more risky areas carry a negative risk premium. This result is consistent with results from the existing literature. One would expect the negative risk premium for houses in risk zone 3 to be greater than the negative risk premium for houses in risk zone 2, but this is not the case. In fact, the negative risk premium is smaller for homes in risk zone 3 than it is for homes in risk zone 2. If people are not aware of relative risk zones, this odd result may be due to other factors that have not been controlled for. The non-significance of $post_t * risk_{ij}$ supports this speculation.

Table II column (2) presents the difference-in-differences estimates of equation (2). The coefficients on bedrooms, bathrooms, house age, and house size are nearly identical to the ones displayed in column (1). Once again, risk is negatively correlated with sales price. Coefficients on the two risk dummies again indicate the percentage decrease in sale price as risk increases from zone 1 to zone 2 and from zone 1 to zone 3, respectively. An increase in risk from zone 1 to zone 3 is associated with a 6.8 percent decrease in sales price, which is equivalent to a $19,918.49 price decrease at the mean. An increase in risk from zone 1 to zone 3 is associated with a 4.6 percent decrease in sales price. This is equivalent to a $13,474.27 price decrease at the mean.

The addition of an after map indicator variable and interaction of this variable with risk zone indicates allows me to test for a differential change in house prices brought about by the publication of the Composite Relative Earthquake Hazard Map of Greater Victoria. The coefficient on $post_t * risk_{ij}$ measures the percentage change in price of house *i* in risk zone *j* that is attributable to the earthquake risk map publication. As can be seen in Table 1, Column 2, the publication of the earthquake hazard map did not affect house sale prices. None of the coefficients indicating map publication or the interaction of map publication with risk zone are statistically significant.

TABLE II: HOUSE SALES 1997-2003

REGRESSION RESULTS FOR FULL SAMPLE OF NEIGHBOURHOODS
(STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLE=LN(PRICE)

Estimated Equation	**(1)**	**(2)**
Bathrooms	0.0671***	0.0673***
	(0.0117)	(0.0117)
Bedrooms	-0.0039	-0.0039
	(0.0079)	(0.0079)
Age of House	0.0002	0.0002
	(0.003)	(0.0003)
House Size (feet^2)	0.0001***	0.0001***
	(0.0000)	(0.0000)
Lot Size (feet^2)	0.00002***	0.00002***
	(0.00000)	(0.00000)
Risk zone 2	**-0.0533****	**-0.0687****
	(0.0219)	**(0.0311)**
Risk zone 3	**-0.0477*****	**-0.0462****
	(0.0162)	**(0.0227)**
After Map	—	**0.0260**
		(0.0458)
(After map)(Risk zone 2)	—	**0.0324**
		(0.0425)
(After map)(Risk zone 3)	—	**-0.0039**
		(0.0425)
Number of obs.	1491	1491
Adj. R^2	0.6310	0.6378

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level

B. Sub-sample of small neighbourhoods

The twelve neighbourhoods included in the full sample are different sizes, geographically. Some, such as Haultain and Rocklands, encompass only a handful of city blocks and could both hypothetically fit inside a large neighbourhood such as Oak Bay South. I control for neighbourhood in my regressions, but I cannot control for unobserved differences between houses within the same neighbourhood. To the extent that houses within small neighbourhoods are likely to be more homogenous, limiting my sample to just smaller neighbourhoods may reduce such unobserved heterogeneity.

Table III presents estimates of equations (1) and (2) using a subsample of 1176 observations that excludes the two largest neighbourhoods of Oak Bay South and Oak Bay Waterfront. Bathrooms, house age, house size, and lot size make nearly the same contributions to house price as they did in the full sample for both specifications. Only risk zone 3 has a statistically significant, negative effect that is slightly smaller in magnitude than previously. Again, the publication of the earthquake hazard map appears to have had no effect on house prices. The results from the subsample of small neighbourhoods are consistent with the results from the full sample.

TABLE III: HOUSE SALES 1997-2003

REGRESSION RESULTS: SUBSAMPLE OF NEIGHBOURHOODS EXCLUDING OAK BAY
(STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLE=LN(PRICE)

Estimated Equation	**(1)**	**(2)**
Bathrooms	0.0791***	0.0788***
	(0.0126)	(0.0126)
Bedrooms	-0.0079	-0.0079
	(0.0085)	(0.0085)
Age of House	0.0006**	0.0007***
	(0.0003)	(0.0003)
House Size ($feet^2$)	0.0001***	0.0001***
	(0.0000)	(0.0000)
Lot Size ($feet^2$)	0.00002***	0.00002***
	(0.0000)	(0.0000)
Risk zone 2	**-0.0351**	**-0.0266**
	(0.0250)	**(0.0355)**
Risk zone 3	**-0.0347****	**-0.0306**
	(0.0169)	**(0.0233)**
After Map	—	**0.0341**
		(0.0485)
(After map)(Risk zone 2)	—	**-0.0171**
		(0.0494)
(After map)(Risk zone 3)	—	**-0.0084**
		(0.0315)
Number of obs.	1176	1176
Adj. R^2	0.5361	0.5351

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level

C. Estimation of earthquake risk salience

Studies have shown that salience matters for behavioural responses to information. Chetty, *et al*. (2012) provide evidence that the public's understanding of wage subsidies in the US Earned Income Tax Credit has spread slowly (over many years). Salience tends to increase over time as people learn from each other and make decisions based on learned information. An article about the Composite Relative Earthquake Hazard Map was published on the front page of Victoria's main newspaper, the Times Colonist, on May 5, 2000. It may have taken several years for people who did not see the newspaper article to become aware of the information, process its importance, and consider relative earthquake hazard when purchasing a home. It is also possible that people consider the risk of an earthquake too small to justify the information gathering and implementation costs of studying the map and factoring the information into bids.

The original sample estimated in Table II includes house sales from January, 1997 to December, 2003. I estimate an alternate sample of house sales between January 1997 and May 5, 2000; and January, 2010 and December, 2012. There is a 32-month span between the control group and the treatment group to allow for diffusion of information. The magnitudes on the risk indicator variables would be greater than in Table II if there were greater salience for the more recent treatment group. As displayed in Table IV, I do not find evidence suggesting that earthquake hazard awareness increased over time. The coefficients on risk have negative significance and but are quite similar to those in Table II.

TABLE IV: HOUSE SALES 1997-2000 & 2010-2012

REGRESSION RESULTS: FULL SAMPLE OF NEIGHBOURHOODS (STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLE=LN(PRICE)

Estimated Equation	**(1)**	**(2)**
Bathrooms	0.0540***	0.0540***
	(0.0091)	(0.0091)
Bedrooms	-0.0079	-0.0079
	(0.0062)	(0.0062)
Age of House	0.0002	0.0002***
	(0.0001)	(0.0002)
House Size (feet^2)	0.0001***	0.0001***
	(0.0000)	(0.0000)
Lot Size (feet^2)	0.00002***	0.00002***
	(0.0000)	(0.0000)
Risk zone 2	**-0.0603*** **	**-0.0684** **
	(0.0178)	**(0.0291)**
Risk zone 3	**-0.0449*** **	**-0.0479** **
	(0.0132)	**(0.0212)**
After Map	—	**0.0251**
		(0.0256)
(After map)(Risk zone 2)	—	**0.0134**
		(0.0357)
(After map)(Risk zone 3)	—	**0.0045**
		(0.0255)
Number of obs.	2010	2010
Adj. R^2	0.7938	0.7935

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level

D. Estimation of house-age divided sub-samples

Although I control for house age in equations (1) and (2), I cannot state definitively whether old houses and new houses respond similarly to earthquake damage. In addition, people's perceptions of relative safety differences between old houses and new houses may drive the results found in Table II. I estimate equations (1) and (2) for subsamples of young and old houses by splitting the total sample of 1491 houses at the mean house age of 72 to allow for this possibility.

Table V presents the estimation results; columns (1) and (2) give estimates of (1) and columns (3) and (4) give estimates of equation (2). House age negatively affects house value in subsamples of young houses, but has a statistically insignificant effect on house prices in subsamples of old houses. House age does not appear to be driving the negative risk premium associated with higher risk zones since the estimates I obtain in columns (1) and (2) are fairly similar to each other. As before, house value does not appear to be affected by the publication of the earthquake risk map.

TABLE V: HOUSE SALES 1997-2003

REGRESSION RESULTS: SUBSAMPLES OF OLD AND NEW HOUSES
(STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLE=LN(PRICE)

	(1) Age>71	(2) Age<72	(3) Age>71	(4) Age<72
Bathrooms	0.0863***	0.0036**	0.0867***	0.0367**
	(0.0169)	(0.0165)	(0.0170)	(0.0165)
Bedrooms	-0.0042	-0.0051	-0.0039	-0.0050
	(0.0111)	(0.0112)	(0.0111)	(0.0113)
Age of House	-0.0004	-0.0029***	0.0003	-0.0029***
	(0.0010)	(0.0002)	(0.0010)	(0.0006)
House Size ($feet^2$)	0.0001***	0.00006***	0.0001***	0.00006***
	(0.0000)	(0.0002)	(0.0000)	(0.00002)
Lot Size ($feet^2$)	0.00002***	0.00002***	0.00002***	0.00002***
	(0.0000)	(0.0000)	(0.00000)	(0.00000)
Risk zone 2	**-0.0235**	**-0.0670****	**-0.0559**	**-0.0843****
	(0.0329)	**(0.0289)**	**(0.0457)**	**(0.0421)**
Risk zone 3	**-0.0471****	**-0.0421***	**-0.0653***	**-0.0251**
	(0.0234)	**(0.0222)**	**(0.0327)**	**(0.0315)**
After Map	—	—	**0.0299**	**0.0264**
			(0.0666)	**(0.0624)**
(After map)(Risk zone 2)	—	—	**0.0726**	**0.0319**
			(0.0632)	**(0.0561)**
(After map)(Risk zone 3)	—	—	**0.0229**	**-0.0334**
			(0.0042)	**(0.0414)**
Number of obs.	746	745	746	745
Adj. R^2	0.5859	0.6905	0.5854	0.6899

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level

E. Price regressed on risk

I control for all house characteristics provided in the Landcor data set, but I cannot rule out the possibility that I omit a variable that is correlated with both risk zone and house price. There may be characteristics about houses in risk zone 1 that make them attractive and relatively safer. Omitted variables such as view type, foundation type, and seismic upgrading may bias the coefficients on risk zones presented in the previous tables.

I control for both property size and lot size in my hedonic regressions, but the correlation between both these measures and relative risk may suggest that there is something else I do not control for that is correlated with both safety and desirability. If, for example, houses built on rocky outcrops are more desirable (due to view type) and safer, failing to control for view type may negatively bias the coefficients on risk. It is likely that waterfront houses are built on solid rock leftover from years of erosion. These houses may command both a safety premium and a waterfront premium. Not controlling for waterfront may negatively bias the risk coefficients.

I regress both house size and lot size on risk zones in Table VI columns (1) and (2), respectively. Houses in risk zone 2 are smaller than houses in risk zone 1 by approximately 197 square feet and houses in risk zone 3 are smaller than houses in risk zone 1 by approximately 255 square feet, on average. Properties in risk zone 2 are smaller than properties in risk zone 1 by approximately 529 square feet and properties in risk zone 3 are smaller than properties in risk zone 1 by approximately 1482 square feet, on average.

TABLE VI: HOUSE SALES 1997-2003

REGRESSION RESULTS: FULL SAMPLE OF NEIGHBOURHOODS
(STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLES= (HOUSE SIZE) FOR COLUMN (1) AND (LOT SIZE) FOR COLUMN (2)

	(1)	(2)
Risk zone 2	-197.28***	-528.65***
	(32.21)	(0.0091)
Risk zone 3	-255.24*	-1431.80***
	(48.83)	(229.15)
Number of obs.	1491	1491
Adj. R^2	0.0192	0.0244

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level

It is also possible for omitted variables to positively bias the coefficients on risk. Common materials used in foundations include but are not limited to pressure-treated wood, stone, and concrete. These materials will perform differently under different environmental conditions (Real Estate Council of British Columbia, 2012). Foundations that perform well in relatively hazardous areas with potential ground amplification, soil hazard potential, or slope hazard may command a safety premium. This positive safety premium would offset the negative risk premium. In addition, the omission of seismic upgrade and foundation improvement variables would positively bias the coefficients on risk because they too require a safety premium.

5. Conclusion

Using a hedonic pricing approach that measures the implied marginal price changes of composite relative risk zones, I find that risk is negatively capitalized into home values. On average, homes in risk zone 2 are discounted by approximately 5.3 percent, and that homes in risk zone 3 are discounted by approximately 4.8 percent when compared to homes in risk zone 1. These percentage decreases imply respective negative price changes of $15,524.70 and $14,060.11 at the mean. These results are robust to estimations on subsamples of only small neighbourhoods, and subsamples separating young and old houses.

I also find that the earthquake risk map publication had no effect on home values. People may have known about the risk zones, perhaps due to some observational factors, before the map publication. My findings may also suggest that either the differences between risk zones are negligible or that people do not know about the earthquake map. Disaggregating the risk measures (soil liquefaction, ground amplification, and slope hazard) may provide insights not apparent from the composite measure.

If people are truly not aware of the relative risk zones within Greater Victoria, there could be an information problem. People do not have the opportunity to purchase full insurance, in part due to high insurance deductibles. With full information, however, people could self-select into relatively safer areas or partake in earthquake retrofits[8] to mitigate potential damage.

[8] For more information, see Reducing Earthquake Damage to Your Home at http://www.earthquakescanada.nrcan.gc.ca/info-gen/prepare-preparer/eqresist-eng.php

A more comprehensive data set including foundation type, frame type, and view type, among other characteristics, could correct the omitted variable bias discussed in section 4. Furthermore, regression discontinuity design may be ideal for eliminating possible heterogeneity. This method restricts the sample to houses within a small bandwidth of earthquake risk borders. If people have not been able to accurately self-select into desired risk zones, the variation in risk treatment would, as a byproduct, be randomized (Lee & Lemieux, 2009).

Another instinctive extension of my findings would include a thorough investigation of the salience of earthquake risk information. Emerging literature reveals that economic behaviour indicating policy understanding differs across time and space, perhaps because of inattention. (Chetty *et al.,* 2012). People learn from one another, but the diffusion of information may be a slow process. By examining negative risk premiums in different neighbourhoods across time, one may gain information on how risk information is processed and shared.

While I find evidence of negative price discounting in relatively riskier areas, I also observe that people do not respond predictably to the introduction of new earthquake risk information. Supplementary investigation in the salience of this information accompanied by an improved data set may justify government intervention. Of course, the inevitable redistribution of wealth caused by such an intervention must also be considered. Examining the effects of relative earthquake risk on housing prices provides a starting-point for several important and interrelated research avenues.

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Appendix

Table VII presents the estimates of the following equation:

$$\ln(price_{it}) = \alpha + X_{it}\gamma + N_j\phi + Z_t u_{it} \quad (4)$$

$\ln(price_{it})$ is regressed on the full sample of 1491 observations, but risk is not included as a regressor. Bathrooms, house size, and lot size are statistically significant and positively related to home values, as expected. The magnitudes of the coefficients on these significant regressors are virtually identical to the magnitudes presented in Table II.

TABLE VII: HOUSE SALE 1997-2003

REGRESSION RESULTS: FULL SAMPLE OF NEIGHBOURHOODS
(STANDARD ERRORS ARE IN PARENTHESES)

DEPENDENT VARIABLE=LN(PRICE)

Estimated Equation	(1)
Bathrooms	0.0664***
	(0.0117)
Bedrooms	-0.0046
	(0.0079)
Age of House	0.0002
	(0.0003)
House Size ($feet^2$)	0.0001***
	(0.0000)
Lot Size ($feet^2$)	0.00002***
	(0.0000)
Number of obs.	1491
Adj. R^2	0.6286

* Indicates statistical significance at the 10% level
** Indicates statistical significance at the 5% level
*** Indicates statistical significance at the 1% level