Seismic Retrofit Added 17% to the Resale Value of Older California Houses

Keith Porter, Ph.D., P.E.[1]; Jasem Alhumaidi[2]; and Zachary Reed[3]

Abstract: We examined the resale prices of 217 recently sold California single-family dwellings built before 1960 to determine whether buyers value seismic retrofit. Of these, sellers indicated that 29 houses had been seismically retrofitted: 17 pre-1940 houses (when unanchored foundations and unbraced cripple walls were common) and 12 built between 1940 and 1959 (when unbraced cripple walls were common). A stepwise regression analysis indicates that in 2020 California home buyers paid 17% more for retrofitted pre-1940 houses. Buyers may have paid about 1% more for retrofitted 1940–1959 houses, but the correlation is weak. A higher resale price is a powerful incentive for people to invest in foundation bolts and cripple wall bracing. It reinforces findings by other researchers that natural hazard mitigation not only *saves* (by avoiding future losses), but it also *pays* (through higher resale value). **DOI: 10.1061/(ASCE)NH.1527-6996.0000579.**

Introduction

Californians know they live in earthquake country. When they buy a house built before 1960, they learn through a mandatory disclosure form and pamphlet (most recently, California Seismic Safety Commission 2020) whether their house has certain seismic deficiencies, including whether it lacks bolts that secure it to the foundation (common before about 1940), and whether it has unbraced cripple walls (common before about 1960). Both problems can be fixed at a cost on the order of a few thousand dollars. But, with a few notable exceptions, the cost burden falls entirely on the owner and California law requires neither buyer nor seller to fix the problems.

Should an owner bolt an old house to its foundation and brace the cripple walls? Earthquake experts and public-safety advocates frequently advise people to do so. The aforementioned pamphlet bases its arguments on preventing injuries and costly property damage; that is, that the retrofit will reduce the owner's loss if an earthquake occurs during the ownership period. Other sources offer a business case for retrofit, in terms of the cost-benefit ratio. For example, the Multi-Hazard Mitigation Council (2019) estimates that spending $1 to seismically retrofit soft-story woodframe multifamily dwellings avoids $12 of future loss, on a long-term average basis, accounting for earthquake occurrence probabilities.

Neither reason to retrofit is perfect. First, the average US homeowner own their home for about eight years (Guerin 2019). In the San Francisco Bay Area, the chance of a magnitude 7 or larger earthquake in the next eight years is about 17%, meaning that if one retrofits one's house, the effort will not save the owner anything five times out of six. The long-term average savings are real and do outweigh the cost, but the investment is still a gamble that probably will not pay off for any one particular owner. Second, the owner makes the investment, but even if the earthquake occurs, some savings go to tenants, insurers, lenders, and others who did not pay for the retrofit, which seems unfair.

In this work, we examine evidence that might support a different, complementary argument to retrofit. We often say that mitigation *saves*, but it might also *pay*. The present work was inspired by recent research by Awondo et al. (2016, 2019), who studied the resale price of recently sold existing single-family dwellings in four coastal Alabama communities frequently threatened by hurricanes. They found that buyers paid up to 25% more for houses near the Alabama coast that had IBHS FORTIFIED Home Hurricane ("Fortified") certifications, and 7% more on average over four Alabama communities.

We wondered if the same were true for earthquake resilience, and set out to imitate Awondo's study as closely as possible. We asked the question: If one owns a pre-1940 house that lacks foundation bolts and braced cripple walls, or a pre-1960 house with unbraced cripple walls, does seismic retrofit have a market value? A seismic retrofit can reduce loss if an earthquake occurs during one's ownership period. But might it also represent a more certain investment, paying for itself by an increased sale price?

We rely solely on publicly accessible real estate sales data, supplemented with household income data from the US Census and a real estate market price index as additional explanatory variables. We do not attempt to address the important, but separate, question of why. That is, we did not speak with sellers or real estate professionals to understand their decisions of whether and how to signal that a property has been seismically retrofitted, or with buyers to understand whether, why, or to what degree they value seismic retrofit. We did not speak with real estate appraisers to discover whether and how they consider retrofit in valuing a home. We ignored other important classes of real property, and other real estate transactions, such as renting or leasing. We considered only houses sold in the greater Los Angeles region and the San Francisco Bay Area, which together represent about 80% of California's housing stock.

We ignore the avoided future losses associated with retrofit, a separate topic that has been treated elsewhere. We mostly ignore insurance and other incentives and do not attempt to quantify risk attitude. We focus almost exclusively on resale value.

[1]Chief Engineer, Institute for Catastrophic Loss Reduction, London, ON, Canada N6C 1K1 (corresponding author). ORCID: https://orcid.org/0000-0003-3025-6114. Email: kporter@iclr.org

[2]Instructor, College of Engineering and Technology, Egaila, Kuwait. Email: Jasem.AlHumaidi@aum.edu.kw

[3]Graduate Student, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado Boulder, Boulder, CO 80309. ORCID: https://orcid.org/0000-0002-9263-526X. Email: zachary.reed@colorado.edu

Note. This manuscript was submitted on October 25, 2021; approved on May 24, 2022; published online on August 26, 2022. Discussion period open until January 26, 2023; separate discussions must be submitted for individual papers. This paper is part of the ***Natural Hazards Review***, © ASCE, ISSN 1527-6988.

Literature Review

Pricing Parameters Used by Real Estate Professions

What features do real estate professions think matter to the asking price of a house? Although Zillow.com (2021) does not track all of the real estate features identified in the Multiple Listing Service (MLS; see mls.com), it allows one to search a larger geographic area than MLS, to search by address, and other advantages that make the data collection required for this study practical. The leading property features that Zillow shows—the ones that literally lead the listing—include number of bedrooms, number of bathrooms, living area, and the street address. Secondary features—the ones that a visitor must scroll down to see—include attached or detached, number of garage spaces, year built, homeowner association fees, kind of heating, lot area, and kind of cooling. Zillow also offers a number of tertiary attributes that require another click to view. These can include a list of the kitchen appliances that are included, kind of flooring, number of stories, whether the home has a swimming pool, a few material features such as exterior wall cladding and roofing material, and others.

Studies of the Market Value of Resilience Features

Several authors have used home sale prices with multivariate linear regression analysis to search for evidence that people value resilience measures. Palm (1981) analyzed resale prices of several thousand homes before and after the passage of California's Alquist-Priolo Geologic Hazards Zones Act in 1973 that required (among other things) disclosure that a home was inside an Alquist-Priolo special studies zone; that is, near a large active fault. Palm examined a total of 7,000 sales in 1972 and 1977, looking for a market effect of the special studies zones, and generally finding none. She also surveyed real estate agents and home buyers about their attitudes about buying properties within the special studies zones. She found that proximity to faults had no effect on home prices. Survey responses suggested that home buyers believe that all of California is at risk of earthquake damage, whether a few tens of meters from a fault or outside a special studies zone. Responses also suggested that home buyers disparage environmental information that real estate professionals give them, because they think the agents simply want to sell the property. Finally, the survey found that many real estate agents do not fully understand the meaning of earthquake fault zones, and thus downplay their importance when selling a property.

Brookshire et al. (1985) performed a similar study, using price data of 1,037 home sales in special studies zones and 10,000 outside. They found that those close to large active faults suffered resale value penalties of 3% to 6%. Brookshire et al. (1985) appeared to be unaware of Palm's (1981) journal article and did not attempt to reconcile their findings with hers.

Simmons and Kruse (2000) performed similar analyses for hurricane resilience. They examined 1,800 records of existing home sales over a six-year period in an unnamed Gulf Coast community using MLS data that indicated, among other features, the presence or absence of storm shutters. Three subsets of their MLS data (for portions of the community on the mainland, on an island, and at a resort) indicated a −5.8%, +4.1, and +17% premium, respectively, for houses with storm shutters. The first of these failed a test of the null hypothesis (that storm shutters correlate with resale value) with a p-value of 0.64, meaning it is more likely than not that the apparent negative correlation was illusory. In the other two cases, the p-values were 0.052 and 0.001, meaning that the null hypothesis could be rejected with high confidence. In another analysis, Simmons et al. (2002) found a 5% increase in resale price for houses with storm shutters, with a p-value of 0.0029. Simmons and Sutter (2007) later found that a tornado shelter added 4% to the resale value of 400 homes in Oklahoma City in 2005, six years after deadly tornadoes struck in May 1999, and after the Oklahoma Saferoom Initiative increased public awareness of tornado shelters.

Awondo et al. (2016, 2019) estimated the value of hurricane risk mitigation on home resale value in Alabama. They too used a hedonic pricing model (that is, people's willingness to pay for a feature as indicated by sale price). They used data acquired from CoreLogic on houses sold in Baldwin County, Alabama between 2004 and 2017, some of which had the Fortified designation. Their dependent variable was the natural logarithm of the sale price. Their independent variables: Fortified designation, coastal distance, house living area, lot area, and numbers of bedrooms, bathrooms, and fireplaces. They analyzed a data set of 2,272 houses, of which 236 (about 10%) had the Fortified designation, and found that on average buyers paid 7% more for Fortified houses, and up to 25% more for houses closest to the Gulf coast. It costs about 4% more to retrofit a house to comply with Fortified requirements (about $51 per square meter), suggesting that sellers can make money by retrofitting their houses to comply with Fortified. The authors did not speak with buyers, sellers, or real estate professionals.

Value of Resilience Features for Insurers and Governments

Many insurers place a market value on resilience. For example, Awondo et al. (2019) report that insurers reduce homeowner policy premiums between 16% and 40% for Fortified homes ($368 to $920 per year for an average annual premium of $2,300). The California Earthquake Authority (2021) offers a premium discount on earthquake insurance of up to 25% for retrofitting older houses and manufactured homes, which can amount to $400 per year for an older, single-family dwelling. Currently only about 12% of California homeowners carry earthquake insurance, so the incentive affects a relatively small fraction of homes.

Some governments offer monetary incentives to encourage homeowners to engage in seismic retrofit. The City of Berkeley, California (City of Berkeley 2019) created the Seismic Retrofit Refund Program, which offers homeowners up to 1.5% of the purchase price of their homes to use on voluntary seismic retrofit. The money comes from a transfer tax the buyer pays at purchase. The State of California has also offered various grants and low-interest loans to encourage retrofit (California Residential Mitigation Program 2020; FEMA 1994, p. 88).

Real Estate Market Cycle and Home Prices

Many of the aforementioned works deal with real estate prices, which change over time, so it helps to know something about real estate market fluctuations. Wheaton (1999) shows that real estate prices do not increase smoothly and monotonically, but exhibit a long-term vaguely exponential increase plus shorter-term cycles on the order of seven years long and with fluctuating amplitudes. Such cyclic variation lends itself poorly to linear regression analysis. We therefore consider two leading indices of real estate cost inflation and market cycles. First, the US Federal Housing Finance Agency (2021) provides the FHFA House Price Index, the nation's only collection of public, freely available house price indexes that measure changes in single-family home values, based on data from all 50 states and over 400 American cities that extend back to the mid-1970s. Among these, the All-Transactions House Price Index for California (CASTHPI) is a reasonable metric of inflation and the market cycle for the houses we consider here. Another option is the S&P CoreLogic Case-Shiller Home Price Indices, which reflect the average change in home prices in the US and in each of 20 major metropolitan statistical areas, but its data are copyrighted. (for an example of such an index, see S&P Dow Jones Indices LLC 2021.)

In preliminary research (Alhumaidi 2020), we used a smaller data set, without CASTHPI. We relied instead on year of sale to reflect the effect that time has on market value. In that study, we estimated that retrofit increases resale value by about 10%. The research discussed in the present work increased the sample size, added CASTHPI as an independent variable, and examined subsets of the data (pre-1940 and 1940–1959 construction).

Methods

We collected data about house features, sale price, and some potentially important demographic data from three sources: Zillow.com, the US Census, and the US Federal Housing Finance Agency (2021).

Zillow.com provides house and other market information that real estate agents generally give to buyers, such as address, house size, number of bedrooms and baths, asking price, and other features that buyers generally care about. (One can access the records of houses after they are sold to obtain their actual sale prices.) Zillow also provides similar information about nearby comparable houses, which gives buyers a sense of the nearby market options, including the selling price of those nearby homes. Real estate professionals use the terms comparable sale, comparable, or simply comp, to mean a nearby, recently sold home similar in location, size, condition, and features such as number of bedrooms and baths. Goldchain and Dobson (2017) suggest that comparable properties are those "sold within the last 90 days . . . [but] if there aren't enough sales a lender might go back six to 12 months." Lyons (n.d.) suggests that the best comps are those that were sold within the last six months or so, have an area within about 30 m^2 (300 sq ft) of the house for sale, and are located within a few hundred meters of the property being sold. Zillow generally offers comparables that meet these criteria, with the exception of date sold: Some comps were sold many years earlier.

Zillow.com does not provide a distinct data field about seismic retrofit (nor does MLS). It provides a free text description (meaning that the real estate professional can write a text description rather than filling in fields or choosing among options), which we searched for the keywords "seismic," "earthquake," and "retrofit." We set a binary retrofit variable to 1 (true) if it seemed likely that most buyers would interpret the text to mean that retrofit work had been done (completed, not merely planned or permitted) to increase the seismic resistance of the house. Still, some retrofitted houses may be overlooked using these search parameters. For example, the listing could mention that the house has been "remodeled" or that work has been done to "strengthen the foundation," without using any of the three keywords. Possibly the remodeling or strengthening work was done to improve seismic resilience; possibly not. It seems more prudent to assume that, unless the description actually uses one of the keywords, buyers would not perceive the work as intended for seismic resistance. And, even if seismic strengthening were the true intent, this analysis seeks to assign a market value to the buyer's perception of seismic strengthening, not the seller's knowledge.

Federal Financial Institutions Examination Council (FFIEC 2020) provides median household income in the house's census tract (we used Google Earth to geolocate each house to find its census tract), which we thought might matter to the selling price. US Federal Housing Finance Agency (2021) provides a statewide index to home sale prices, meaning that it serves as a proxy for the real estate market cycle, that is, the average effect of time on home sale prices. See Table 1 for the variables we collected.

We searched Zillow for the keywords and compiled data for all seismically retrofitted single family dwellings for sale at the time of the research (between about April and July 2020) in California. For each retrofitted house, we also compiled the same data for 10 or so comps, generally the ones Zillow offered.

While houses are for sale, Zillow records the asking price, whereas the comparable sales display the actual selling price. We returned to Zillow after the retrofitted houses were sold to replace asking price with actual sale price, and performed the analysis on sale price. As an aside, the average ratio of sale price to asking price was 1.016. Its standard deviation was 0.13, meaning that the average retrofitted house sold for 1.6% ± 13% over asking. The comps had all been sold, and Zillow did not show their asking price.

We performed a multivariate linear regression analysis of the natural logarithm of the sale price as a function of the independent variables. Why the natural logarithm of price and not price itself? Three reasons: (1) in imitation of and for comparability with prior research, (2) for generality, because the coefficients approximately express (unitless) percent change in price rather than dollar value of the feature (i.e., in units of dollars), and (3) we did regress price itself without notable improvement in explanatory power.

We used stepwise regression analysis to identify only the most statistically significant independent variables. Stepwise regression starts with no independent variables in the model and adds variables in decreasing order of added predictive power until none improves the model to a statistically significant extent. It controls for correlation between independent variables. People sometimes criticize stepwise regression analysis for substituting intense computation for subject area expertise, a charge also laid on machine learning. As used here, however, it merely adds to the real estate expertise reflected in Zillow's (fairly standard) choice of market parameters. The procedure is standard enough not to require more explanation here; the interested reader can see, for example, Wilkinson (1979) for a general treatment of stepwise regression analysis.

The result of the analysis is a mathematical model of the form shown in Eq. (1), where y denotes sale price, a denotes a constant coefficient, i denotes an index to n independent variables, x denotes an independent variable, and e denotes an error term

$$\ln(y) = a_0 + \sum_{i=1}^{n} a_i x_i + e \qquad (1)$$

For the reader who is unfamiliar with multivariate linear regression analysis, some notable parameters: The p-value of a variable reflects the probability that the null hypothesis is correct (that is, that the parameter does not actually relate to the dependent variable). We excluded variables whose p-value exceeds 0.15. The goodness of fit for the model as a whole has several notable parameters: The coefficient of determination, denoted R^2, reflects the fraction of marginal variance (the variance of the dependent variable in the data set) that the regression analysis explains. The R^2 adjusted reduces R^2 to account for the spurious correlation introduced by additional independent variables. The standard error of the regression, S, represents the average distance that the observed values fall from the regression line, in the same units as the response variable. See most statistics textbooks for more insight into multivariate linear regression, e.g., NIST and SEMATECH (2013).

We performed the regression analyses using houses built before 1940, when houses commonly had two important seismic deficiencies. They commonly lacked positive connection—usually

Nat. Hazards Rev., 2022, 23(4): 05022009

Table 1. Data collected

Variable	Unit	Description	Source
Address	N/A	Street address in US Postal Service format. An identifier, not an independent variable for regression analysis.	Zillow, address
Latitude	Deg N	House location decimal degrees north latitude, a point somewhere in the interior of the house footprint, to four decimal places.	Google Earth
Longitude	Deg E	House location decimal degrees east longitude (negative in the US), a point somewhere in the interior of the house footprint, to four decimal places.	Google Earth
Tract	N/A	11-digit US Census tract code: SS-CCC-TTTT.TT, where SS = state code, CCC = county code, TTTT.TT = tract code. An identifier, not a variable for regression analysis.	FFIEC.gov Geocoding/Mapping System
Price	Dollar	The price of the dwelling at the time of the most recent sale, in dollars of that year. For retrofitted houses, one returns to Zillow.com months later, after the houses are sold.	Zillow, Zestimate history, most recent value of "Sold for"
Retrofit	Binary	0 if no mention of seismic retrofit; 1 if house is reported to have had seismic retrofit.	Zillow Overview; see subsequent note on keywords.
Year sold	Year	Year of the most recent sale.	Zillow, Zestimate history, year of most recent sale
CASTHPI	N/A	All-Transactions House Price Index for California.	US Federal Housing Finance Agency (2021)
Year built	Year	Year built.	Zillow, Facts and Features, year built
Age at sale	Year	The age of the house at the time of the most recent sale.	Calculated
Lot size	Sq ft	The area of the lot on which the house was built.	Zillow, Facts and Features, Lot
House size	Sq ft	Total interior livable area.	Zillow Interior Details, Total interior livable area
Bedrooms	Each	Number of bedrooms.	Zillow, Interior Details, Bedrooms
Bathrooms	Each	Number of bathrooms.	Zillow, Interior Details, Bathrooms
Fireplaces	Each	Number of fireplaces, if shown. Blank if not provided. Enter 1 if Zillow says "yes"; enter 0 if Zillow says "none."	Zillow, Interior Details, Fireplace Database
A/C unit	N/A	The type of air condition units installed in the property. Three categories are used, indexed by 0 to 2, as follow: 0: no air conditioner. 1: Window air condition unit 2: Central air conditioning.	Zillow, Facts and Features, Cooling
Garage width	N/A	1 = 9-ft door, 2 = 16-ft door.	Zillow, Property Details, Parking
Parking spaces	N/A	The number of parking spaces that the property provides, whether that be a garage or street parking. Zillow does not categorize the type of parking space. Blank if not provided.	Zillow, Property Details, Parking
Improved	Binary	Home Details Overview contains one or more of the following words: renovate, remodel, update, or upgrade, except for seismic improvements.	Zillow, Home Details overview
Household income	Dollars	2015 census tract median household income.	FFIEC geocoding/mapping system, 2015 tract median household income

bolts—between the foundation and the sill plate (a strip of wood placed on the foundation, and upon which the rest of the house rests). And they commonly had unbraced cripple walls, meaning the short walls between the foundation and first floor were weak. We repeated the analysis for houses built between 1940 and 1959, when foundation bolting was the norm, but many houses were still built with unbraced cripple walls.

We did not analyze the complete data set for pre-1960 as a whole for two reasons. First, the decision situations differ notably: A pre-1940 house generally requires a more extensive and costly retrofit than does a 1940–1959 house. Second, virtually every buyer and seller knows the approximate year of construction, so we see little value answering a question nobody would ask if they could get an answer more tailored to their decision situation.

Findings

Number of Observations

In summer 2020, Zillow showed 40 California single family dwellings listed for sale with indications that they had been seismically retrofitted. Zillow typically offers 10 comparables for each house. In a few cases we selected comparables ourselves, sometimes because Zillow did not offer exactly 10, sometimes because we selected nearby single-family dwellings for sale, rather than relying on Zillow's suggested comparables. We tried not to stray too far from either Zillow's practice or from Awondo's example. Awondo's data set included 2,276 houses, of which 236 had the FORTIFIED certification, or about nine comparable non-FORTIFIED houses per FORTIFIED house. We added 478 non-retrofitted comparable sales, i.e., $N = 518$. Thus, the set contains about 12 comparable non-retrofitted houses per retrofitted house.

Of the 40 houses with reported seismic retrofit, 17 were reportedly built before 1940. Another 12 were reportedly built between 1940 and 1959. All the retrofitted houses were for sale in the spring and summer of 2020. Of 478 non-retrofitted comparables, 188 were sold after 2018. We included 2019 and 2018 sales, on the assumption that the CASTHPI would at least partially account for the real estate market cycle, and later tested our findings excluding 2018 sales and then also excluding 2019 sales, without finding much difference in the coefficient for retrofit. Table 2 shows sample size by era of construction.

Table 2. Sample size by era of construction

Count	Year of construction	
	Pre-1940	1940–1959
Retrofitted	17	12
Comparables (non-retrofitted)	98	90
East Bay: Alameda and Contra Costa Counties	57	25
South Bay: Santa Clara County	2	15
Peninsula: San Francisco and San Mateo Counties	25	32
Southern California: Los Angeles, Orange, Riverside, San Bernardino, and Ventura Counties	24	30
Others: Solano and Humboldt Counties	7	0

Results of the Regression Analyses

We performed stepwise linear regression analyses of the natural logarithm of the sale price against the independent variables listed in Table 1. We performed two analyses: one of the pre-1940 houses and one of the 1940–1959 houses. See Table 3 for the first model and Table 4 for the second. In both tables, the column labeled i denotes the order in which independent variables were added during the regression analyses. It also refers to the subscript in Eq. (1). "Term" refers to the terms x_1, x_2, etc., and "coefficient" to the coefficients a_1, a_2, etc., except of course that the coefficient for the row labeled "Constant" refers to a_0. "SE" refers to the standard error of the coefficient, a measure of how uncertain it is. Columns labeled p-value, S, R^2, and $R^2\,(adj)$ are as described earlier. Table entries for S, R^2, and $R^2\,(adj)$ reflect the model when all variables up to and including only that variable (i) are used in the model, but not the ones in lower rows.

Retrofit appears to matter to the sale price of pre-1940 houses, adding 17% to the resale value (its coefficient was 0.168). We tested the robustness of this finding to stricter constraints on the year of sale, including only sales in 2020, and only sales in 2019 and 2020. The coefficient for retrofit rose slightly. The p-value of 0.031 means that we can reject with high confidence the null hypothesis that the correlation is accidental.

Retrofit does not appear to matter to the resale price of 1940–1959 houses, at least not with high confidence. When one forces its inclusion in the model for 1940–1959 houses, its coefficient is 0.01, meaning the best estimate is that it added 1% to the resale value. But, its standard error was 0.074 and its p-value was 0.88, meaning that there is a high chance that the correlation between retrofit and price is illusory. Both models have high predictive power, explaining about 80% of marginal variance.

Interpretation of Model Terms

A few parameters predictably matter to home sale price: household income, location, house size, lot size, and the market cycle (here, CASTHPI). Retrofit appears in Table 3 and seems to add 17% to the sale price of a house. We reflect on the size of that coefficient later. Number of bedrooms, baths, and parking spaces do not appear in the model. Bedrooms and bathrooms correlate strongly with house size (more detail on correlation later), so including them as well as house size does not appear to add significantly to the model's predictive power. We hesitate to speculate on why parameters appear in the order they do, and on the relative size of their coefficients. Useful insight on those points seem to require conversations with buyers, sellers, and real estate professionals.

Some Questions Raised Regarding the Research Results

The analysis and these findings raise a number of questions and expose our analyses to important challenges. In the remainder of this work, we raise and respond to some obvious questions and challenges.

Table 3. Best model for pre-1940 houses sold between 2018 and mid-2020 (N = 115 houses)

i	Term	Coefficient	SE	p-value	S	R^2	$R^2\,(adj)$
0	Constant	13.726	0.815	—	—	—	—
1	Household income	0.000003	0.000001	0.000	0.435	43.2%	42.7%
2	Peninsula	1.238	0.092	0.000	0.374	58.4%	57.6%
3	House size m^2 (sq ft)	0.00390 (0.000362)	0.000560 (0.000052)	0.000	0.340	66.0%	65.1%
4	East Bay	0.669	0.068	0.000	0.275	77.9%	77.1%
5	South Bay	0.613	0.191	0.002	0.266	79.6%	78.6%
6	Garage	−0.07	0.0353	0.050	0.262	80.4%	79.3%
7	Lot size m^2 (sq ft)	0.000172 (0.000016)	0.000075 (0.000007)	0.022	0.257	81.2%	80.0%
8	Improved	0.113	0.054	0.038	0.253	81.9%	80.6%
9	Retrofitted	0.168	0.077	0.031	0.250	82.8%	81.1%
10	CASTHPI	−0.002	0.001	0.088	0.250	82.8%	81.2%

Table 4. Best model for 1940–1959 houses sold in 2018 to mid-2020 (N = 102 houses)

i	Term	Coefficient	SE	p-value	S	R^2	$R^2\,(adj)$
0	Constant	25.8	8.21	—	—	—	—
1	Southern California	−0.619	0.089	0	0.346	47.2%	46.6%
2	East Bay	−0.460	0.058	0	0.299	60.9%	60.1%
3	Household income	0.000005	0.000001	0	0.247	73.5%	72.7%
4	House size m^2 (sq ft)	0.00211 (0.000196)	0.000689 (0.000064)	0.003	0.232	76.8%	75.9%
5	CASTHPI	0.005	0.002	0.005	0.224	78.7%	77.6%
6	Year of construction	−0.008	0.004	0.048	0.222	79.3%	78.0%
7	Lot size m^2 (sq ft)	0.000237 (0.000022)	0.000129 (0.000012)	0.071	0.219	80.0%	78.6%

Nat. Hazards Rev., 2022, 23(4): 05022009

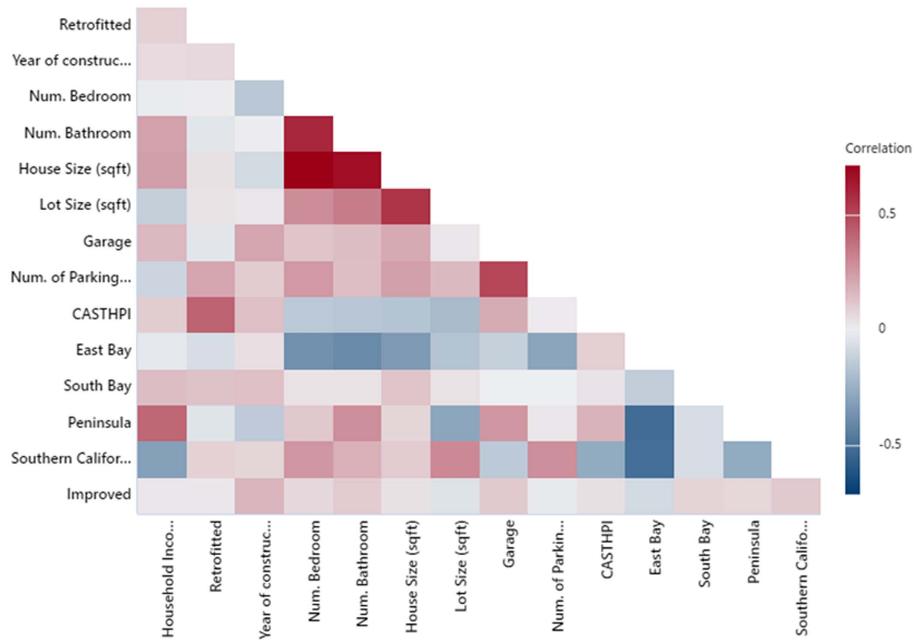

Fig. 1. Correlogram of independent variables examined here.

Challenge 1: Can Retrofit Really Be Worth So Much to Buyers?

This seems like the most challenging problem raised by our research, partly because we did not speak to buyers, sellers, or real estate professionals, or otherwise attempt to understand motivations or decisions (unlike Palm's admirable 1981 study.) We speculate on two possibilities.

First, although price is correlated with retrofit, maybe the increase is not actually caused by the retrofit, but by some other hidden variable that correlates with retrofit. We searched for but could not find support for such a hypothesis. Real estate professionals list the variables they think matter most to sale price, and we have included them. A more important hidden variable would have to escape the notice of the profession whose job it is to understand real estate value. Among all the variables considered here—the ones that real estate professionals think matter—retrofit only correlates strongly with CASTHPI (their correlation coefficient $\rho = 0.42$), as shown in the correlogram of Fig. 1. But the stepwise regression selected retrofit before CASHTPI, meaning that retrofit offers more explanatory power than CASHTPI. Other independent variables that appear in the final model correlate little with retrofit, so they probably do not conceal its effect. A reviewer speculated that retrofit might correlate with the house's general state of repair, which would be hard to reflect in the text of a real estate listing. That and other possibilities could be pursued starting with conversations with buyers, sellers, and real estate professionals.

The second possibility: maybe buyers *did* value retrofit substantially, consistent with the findings of prior hedonic pricing studies of special studies zones, hurricane resilience measures, and tornado shelters. Several things happened in the last few years that could have made buyers anxious about earthquakes and value retrofit substantially as a consequence. Several mandatory soft-story retrofit ordinances went into effect between 2017 and 2020, with notable mandatory requirements in San Francisco (City and County of San Francisco 2013), Los Angeles (Mayoral Seismic Safety Task Force 2014; LADBS 2015a, b), and Oakland (Municode.com 2019). Another possible influence: The US Geological Survey published and widely disseminated the HayWired disaster planning scenario, which depicted a hypothetical catastrophic earthquake in the San Francisco Bay Area (Detweiler and Wein 2017). Statewide media covered the study extensively. And finally, 2017 was the worst disaster year in United States history, costing the nation $319 billion, representing over 25% of the $1.3 trillion in new construction put into place that year (Porter and Yuan 2020). All three factors may have created a sense of risk in buyers' minds that the promise of a completed seismic retrofit would help to dispel. And the fact that several other authors found a similar increase in the purchase price of houses that had some salient resilience feature—storm shutters or Fortified designation in hurricane country or tornado shelters in Tornado Alley—tends to support the hypothesis that buyers do value retrofit.

Challenge 2: Is the Sample Representative of California Housing?

The study required sampling of retrofitted houses and houses that Zillow considered to be comparable to them. Despite the necessary sampling bias, the sampled houses appear to closely resemble the housing stock for sale in California, and at least insofar as Zillow reflects houses for sale in California. See Table 5. The major exception was year built: Retrofitted houses and houses that Zillow considered to be comparable to them are older. Their median year built was 1950, versus a median of 1980 for overall California houses for sale. One could expect such a difference, because people generally do not retrofit houses that have braced cripple walls,

Table 5. Median attributes of sample versus California state

Parameter	Sample	State
Sale price	$738,500	$748,336
2015 median household income	$80,737	$75,235
House size, m^2 (sq ft)	175 (1,885)	172 (1,852)
Year built	1950	1980
Bedrooms	3	3
Baths	2	3
Parking spaces	2	2

which grew common in the 1960s. Why would comparables, which outnumber retrofitted houses in the sample by 11:1, also be older than the statewide median? Because comparable houses tend to be in the same neighborhood as retrofitted houses, and neighborhoods tend to be built in the same era. Note that we estimated statewide medians by filtering Zillow's listings of all California houses for sale by the desired attribute, recording the distribution, and calculating median values. We collected the statewide data on August 1, 2021, about a year after we collected the sample data, so some market changes could have occurred. Still, the agreement seems reasonable. We took statewide 2015 median household income from the US Census Bureau (2021).

Challenge 3: How Reliable Are the Zillow Data?

One can probably rely highly on the Zillow data. Zillow provides photographs to check the number of bedrooms and bathrooms, presence of garage, and other features. Total house area is approximate: different people arrive at slightly different sizes for the same house because of errors in room dimensions, including or excluding walls, etc. Presumably something similar holds for lot size. Also, year built may be an estimate arrived at by judging architectural style and familiarity with the development of the neighborhood. However, we assumed that the Zillow data perfectly represent the actual conditions, or at least that buyer perceptions perfectly agree with Zillow data—that buyers do not perceive differences between Zillow data and the actual house.

Challenge 4: Were Data Excluded from Independent Variables?

Table 1 omits a few house characteristics that Zillow makes available and a few that we could conceivably have compiled from elsewhere, such as number of stories. These variables may affect purchase price, but we omitted them for several reasons. First, we set out to mimic Awondo et al.'s (2019) analysis, and they also omitted these fields. Second, we omitted them to keep data collection manageable and because they seemed less relevant to the present question than other data fields that we did collect. Omitted fields include parcel number, mode of heating, exterior finish material, whether the garage is attached, annual tax amount, neighborhood walkability, neighborhood transit options, and neighborhood school ratings. It seems reasonable to omit neighborhood characteristics because comparable houses are generally in the same neighborhood (the median distance to the retrofitted house was 0.8 km), with the same walkability, schools, and transit options.

Challenge 5: What Other Data Are Out There That We Ignored?

We did not attempt to obtain all records of all houses sold over a longer period of time, as Simmons et al. (2002) did, for example. We made this choice mostly for convenience, but also for the sake of repeatability: We wanted to offer a methodology that anybody could carry out without acquiring proprietary or privileged data. We did not attempt to estimate the expense that buyers had to incur after purchase to make the house move-in quality, such as repainting. One could examine more-recent street-view photos of the houses after purchase (if those photos are available) to see if the house exterior was repainted. One could perform mail surveys to ask buyers and real estate professionals about these and other less-tangible features. We have not done so partly because of the effort involved, partly to imitate Awondo as closely as possible, and partly because no study can answer every relevant question. And one can always go back to Zillow to collect data as more houses enter the market.

Challenge 6: Controlling for Wealth

Conceivably, people who retrofit their houses have more wealth, which could correlate with desirable neighborhood attributes such as schools, walkability, trees, etc., which could correlate in turn with higher house prices. Thus, one might suspect that the apparent price premium for retrofitted houses might actually reflect one or more hidden variable about the neighborhood, rather than reflecting the value of the retrofit. However, the methodology controls for wealth and neighborhood in two ways: First, it includes household income among the independent variables. Second, each retrofitted house is accompanied in the database by approximately 10 comparable houses with similar size and located within the same neighborhood.

Conclusions

We set out to examine whether seismic retrofit increased the resale price of California single family dwellings for sale in summer 2020. We collected real estate sales data about houses whose descriptions on Zillow.com ("the most-visited real estate website in the United States," according to its web page) indicated seismic retrofit, along with similar data about comparable houses for sale or recently sold. The data included 18 other attributes, such as geographic location, house and lot area, number of bedrooms and bathrooms, year built, and neighborhood median household income.

We performed stepwise multivariate linear regression analysis to construct a mathematical model of resale price, and found that seismic retrofit appears to add 17% to the resale price of California homes built before 1940, compared to other houses of the same era of construction that were sold between 2018 and 2020. The finding is far from definitive, however. Correlation is not the same thing as causation. We do not know that sellers actually considered retrofit in setting sale price or that buyers responded to it. We do not know what buyers and sellers were thinking, because we did not talk to any. However, we can reasonably infer that the sellers' real estate agents considered the retrofit to have some value, because they mentioned it in the description of the house. And, it seems noteworthy that the retrofit coefficient was within the 7% to 25% bounds that Awondo et al. (2019) found for hurricane resistance (7% on average, 25% close to the Gulf coast), and on the same order of magnitude as Simmons et al. (2000, 2002) and Simmons et al. (2007) found for storm shutters and tornado shelters.

We and others have copiously demonstrated that natural hazard mitigation *saves*. The present work supports the intriguing hypothesis advanced by prior researchers for other perils that natural hazard mitigation also *pays*. A short-term reliable monetary incentive to seismically retrofit one's house could change the retrofit game in a fundamental way: One would not have to be scared of earthquakes or coaxed by authorities into doing the right thing, but merely invest for the gain.

All of this matters not just to the homeowner, but to all of society. Despite the retirement of older buildings; their replacement by new, code-compliant construction; and public expenditures of $1 billion annually, US disaster losses are increasing geometrically, 10 times faster than the population, at 6% per year. Fig. 2 (Porter and Yuan 2020) shows that disasters now cost the US on average $100 billion per year. In 2017, they cost $300 billion, about $1 for every $4 spent that year on the nationwide construction of new buildings. That growth suggests a fundamental problem in America's design philosophy: We are under-designing: designing inefficiently to minimize first costs for the developer and first owner, at society's much greater expense later on from future losses (Porter 2020). The Multi-Hazard Mitigation Council (2019)

Nat. Hazards Rev., 2022, 23(4): 05022009

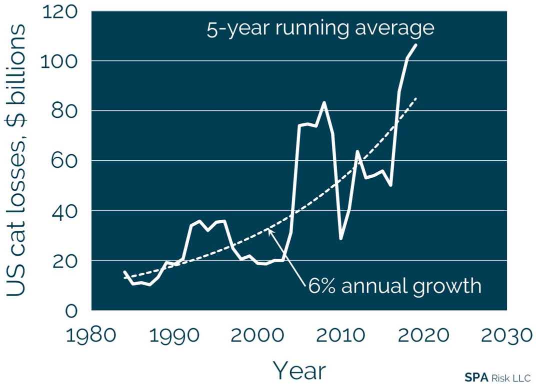

Fig. 2. US catastrophe losses grow 6% per year, 10 times faster than the population. (Reprinted from Porter and Yuan 2020.)

estimates that the nation could cost-effectively spend over $500 billion on disaster mitigation for existing buildings alone. That amount exceeds by 1,000 times the nation's annual public-sector mitigation budget (US Department of Homeland Security 2020), little of which addresses private-sector buildings. Solving our disaster resilience problems with private-sector buildings—reversing what seems like a financially unsustainable growth in disaster liability—must involve changing new designs, and remediating vulnerable existing buildings. To deal with the seismic risk from existing buildings seems to require some combination of three policies: (1) enact nationwide laws or regulations to require retrofit of some existing buildings, (2) wait decades or more for the worst buildings to be demolished through obsolescence or disasters, or (3) mobilize private-sector forces to promote remediation. Option 1 seems laughably improbable. Option 2 seems shamefully irresponsible. The new evidence offered here and in earlier studies by Brookshire, Simmons, Awondo, and their colleagues hints that Option 3 may be practical.

Limitations and Open Questions

We do not know why or exactly how resilience measures affect sale price. We would like to understand the motivations behind market responses to retrofit signals. Are buyers paying more because they value the appearance of greater seismic safety? If so, were they responding to recent events such as mandatory retrofit ordinances, recent disasters, and recent publication of disaster planning scenarios that temporarily increased their sense of risk, a sense that would dissipate a few years later, a phenomenon that Meyer and Kunreuther (2017) call amnesia bias? Can policymakers counter the amnesia bias, perhaps by frequently publishing disaster planning scenarios to remind people of risk?

We raise but do not address these questions here. We can imagine conversations with or surveys of buyers, sellers, or real estate professionals, like those that Palm (1981) carried out. Perhaps one could devise quantitative tests or natural experiments where one can control the single variable of seismic retrofit, or the way that the seismic retrofit is described to the buyer. It would be interesting to see how much influence one can have on the market value of seismic retrofit using the psychology of persuasion, such as described by Cialdini (2021) in his classic book on the subject. And it would be informative to repeat this study periodically over time to test for the onset of amnesia bias, and to study for how long different stimuli (e.g., ordinances, disasters, and planning scenarios) affect the market price of seismic retrofit.

Data Availability Statement

The Zillow data that support the findings of this study are available from the corresponding author upon reasonable request.

Acknowledgments

Some funding for this work was provided by the Institute for Catastrophic Loss Reduction. We thank Althea Cohen-Porter of Columbia University and Nicholas Grant of University of Colorado Boulder, who helped to compile the data used here. Thanks also to Charlie Scawthorn for his critique of our early findings. And thanks to Kevin Simmons, Sebastain Awondo, and Lars Powell for insight on their prior work and for their advice comparing and contrasting this work with theirs.

References

Alhumaidi, J. 2020. "The effects of earthquake retrofit on the resale value of single-family dwellings." Master's thesis, Dept. of Civil, Environmental, and Architectural Engineering, Univ. of Colorado Boulder.

Awondo, S., H. Hollans, L. Powell, and C. Wade. 2016. *Estimating the effect of FORTIFED home construction on home resale value*. Tuscaloosa, AL: Univ. of Alabama.

Awondo, S., H. Hollans, L. Powell, and C. Wade. 2019. "Estimating the effect of wind loss mitigation on home value." *SSRN*. Accessed September 26, 2021. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3330193.

Brookshire, D. S., M. A. Thayer, J. Tschirhart, and W. D. Schulze. 1985. "A test of the expected utility model: Evidence from earthquake risks." *J. Political Econ.* 93 (2): 369–389. https://doi.org/10.1086/261304.

California Earthquake Authority. 2021. "How to qualify for an earthquake insurance premium discount." Accessed June 21, 2021. https://www.earthquakeauthority.com/California-Earthquake-Insurance-Policies/Earthquake-Insurance-Policy-Premium-Discounts.

California Residential Mitigation Program. 2020. "What is EBB?" *Earthquake Brace + Bolt*. Accessed October 23, 2020. https://www.earthquakebracebolt.com/Content/AboutEBB.

California Seismic Safety Commission. 2020. *Homeowner's guide to earthquake safety.* Seismic Safety Commission No. 20-01. West Sacramento, CA: California Seismic Safety Commission.

Cialdini, R. 2021. *Influence: The psychology of persuasion*. New York: Harper Business.

City and County of San Francisco. 2013. "Resilient San Francisco." Accessed September 30, 2021. https://sfgov.org/ccsfgsa/sites/default/files/ORR/documents/Resilient%20San%20Francisco_0.pdf.

City of Berkeley. 2019. "Transfer tax reductions for qualifying seismic retrofit work." Accessed July 25, 2022. https://berkeleyca.gov/construction-development/seismic-safety/funding-seismic-retrofits/transfer-tax-refunds-seismic-work.

Detweiler, S. T., and A. M. Wein. 2017. *The HayWired earthquake scenario—Earthquake hazards*. Scientific Investigations Rep. No. 2017–5013–A–H. Reston, VA: USGS.

FEMA. 1994. *Seismic retrofit incentive programs: A handbook for local governments*. FEMA 254. Washington, DC: FEMA.

FFIEC (Federal Financial Institutions Examination Council). 2020. "Geocoding system." Accessed June 21, 2021. https://geomap.ffiec.gov/FFIECGeocMap/GeocodeMap1.aspx.

Goldchain, M., and A. R. Dobson. 2017. "Appraisals and comps: 9 important things to know." *Curbed*. Accessed October 3, 2021. https://dc.curbed.com/2017/5/15/15642288/appraisals-comps-real-estate-square-footage.

Guerin, J. 2019. "Homeowners are staying put, just not for as long as before." *HW Media*. Accessed October 3, 2021. https://www.housingwire.com/articles/48946-homeowners-are-staying-put-just-not-for-as-long-as-before.

LADBS (Los Angeles Department of Building and Safety). 2015a. "Los Angeles municipal Code Ordinance No. 183893." Accessed September

30, 2021. https://www.ladbs.org/docs/default-source/publications/misc-publications/ordinance_183893.pdf?sfvrsn=cf96e053_6.

LADBS (Los Angeles Department of Building and Safety). 2015b. "Los Angeles municipal Code Ordinance No. 184081." Accessed September 30, 2021. https://www.ladbs.org/docs/default-source/publications/ordinances/14-1697-s2_ord_184081_2-19-16.pdf?sfvrsn=8e28e253_8.

Lyons, J. n.d. "Real estate comps: How to find comparables for real estate." Accessed July 25, 2022. https://www.zillow.com/sellers-guide/real-estate-comps/.

Mayoral Seismic Safety Task Force. 2014. "Resilience by design." Accessed September 30, 2021. https://www.eeri.org/images/archived/wp-content/uploads/Garcetti-Los-Angeles-Earthquake-Plan.pdf.

Meyer, R., and H. Kunreuther. 2017. *The ostrich paradox: Why we underprepare for disasters*. Philadelphia: Wharton Digital Press.

Multi-Hazard Mitigation Council. 2019. *Natural hazard mitigation saves: 2019 report*. Washington, DC: National Institute of Building Sciences.

Municode.com. 2019. Oakland, California Code of Ordinances Title 15 Buildings and Construction Chapter 15.27: Mandatory seismic evaluation and retrofit of certain multi-unit residential buildings." Accessed September 30, 2021. https://library.municode.com/ca/oakland/codes/code_of_ordinances?nodeId=TIT15BUCO_CH15.27MASEEVRECEMUITREBU.

NIST and SEMATECH. 2013. *e-handbook of statistical methods*. Gaithersburg, MD: NIST. https://doi.org/10.18434/M32189.

Palm, R. 1981. "Public response to earthquake hazard information." *Ann. Assoc. Am. Geogr.* 71 (3): 389–399.

Porter, K. A. 2020. "Should we build better? The case for resilient earthquake design in the United States." *Earthquake Spectra* 37 (1): 523–544. https://doi.org/10.1177/8755293020944186.

Porter, K. A., and J. Q. Yuan. 2020. "America's growing disaster liability." *SPA Risk*. Accessed June 21, 2021. http://www.sparisk.com/pubs/Porter-Yuan-2020-Disaster-Liability.pdf.

Simmons, K. M., and J. B. Kruse. 2000. "Market value of mitigation and perceived risk: Empirical results." *J. Econ. Insight* 26 (1): 41–51.

Simmons, K. M., J. B. Kruse, and D. A. Smith. 2002. "Valuing mitigation: Real estate market response to hurricane loss reduction measures." *South. Econ. J.* 68 (3): 660–671. https://doi.org/10.10.2307/1061724.

Simmons, K. M., and D. Sutter. 2007. "Tornado shelters and the housing market." *Constr. Manage. Econ.* 25 (11): 1119–1126. https://doi.org/10.1080/01446190701618299.

S&P Dow Jones Indices LLC. 2021. "S&P/Case-Shiller CA-Los Angeles home price index [LXXRSA]." *Federal Reserve Bank of St. Louis*. Accessed August 4, 2021. https://fred.stlouisfed.org/series/LXXRSA.

US Census Bureau. 2021. "QuickFacts: California." Accessed July 31, 2021. https://www.census.gov/quickfacts/fact/table/CA/INC110219.

US Department of Homeland Security. 2020. "FY 2021 budget in brief." Accessed June 21, 2021. https://www.dhs.gov/sites/default/files/publications/fy_2021_dhs_bib_web_version.pdf.

US Federal Housing Finance Agency. 2021. "All-transactions house price index for California [CASTHPI]." *Federal Reserve Bank of St. Louis*. Accessed August 4, 2021. https://fred.stlouisfed.org/series/CASTHPI.

Wheaton, W. C. 1999. "Real estate 'cycles': Some fundamentals." *Real Estate Econ.* 27 (2): 209–230. https://doi.org/10.1111/1540-6229.00772.

Wilkinson, L. 1979. "Tests of significance in stepwise regression." *Psychol. Bull.* 86 (1): 168–174. https://doi.org/10.1037/0033-2909.86.1.168.

Zillow.com. 2021. "California single family homes." Accessed July 25, 2022. https://www.zillow.com.