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Motivators and impediments to seismic retrofit implementation for wood-frame soft-story buildings: A case study in California

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Abstract
Motivating property owners to mitigate seismic risks for existing buildings is a major challenge for many earthquake-prone regions. This article identifies primary factors that may affect the adoption of seismic retrofit by owners of commercial and residential buildings, assesses the influence of economic, social, regulatory, and individual factors on retrofit implementation in three California cities, and discusses potential approaches to promoting seismic retrofits. Data for three retrofit programs are utilized to create predictive models for retrofit probability. The results suggest that retrofit probability for multifamily residential buildings may increase with building height, median housing value, educational attainment, and population density in the neighborhood, but may decrease with building age, building size, land value, and housing vacancy rate in the neighborhood. The retrofit decision for commercial buildings is strongly correlated with the number of stories and rooms, land value, vacancy rate, and population density, while the retrofit decision for residential buildings is highly associated with building age, number of rooms, land value, median housing value, median contract rent, and educational attainment. Overall, promoting seismic retrofits requires careful consideration of different motivators and impediments to owner's retrofit actions for commercial and residential buildings, and for older, taller, larger buildings, which tend to be more vulnerable but are associated with higher retrofit costs. In addition, neighborhood characteristics including median housing value and vacancy rate may be strong indicators of the retrofit probability among building clusters.

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Introduction

Older buildings tend to collapse or sustain severe damage during a seismic event due to structural deficiencies and cumulative damage resulting from previous events (Grimaz and Malisan, 2017; Mouyiannou et al., 2014). The rapid development of retrofit technologies allows older buildings to be strengthened to withstand a major earthquake (e.g. the 1989 Loma Prieta Earthquake) instead of costly reconstruction. Proactive retrofit is part of risk mitigation policies in California (California Seismic Safety Commission (CSSC), 2002, 2007), where more than half of jurisdictions in high-seismicity regions established a retrofit program for unreinforced masonry buildings (URM) after the issuance of the 1986 State Law (CSSC, 1995). The targeted buildings have been expanded to include wood-frame soft-story buildings, nonductile, and tilt-up concrete structures, and steel moment frames as significant damage and some collapses were observed in recent earthquakes (City of Los Angeles, 2015; City of San Francisco, 2013).

Despite increasing awareness of the vulnerability of older buildings, property owners are often reluctant to undertake mitigation measures. Some studies attribute reluctance to high retrofit cost, long payback period, and insufficient financial incentives (Egbelakin et al., 2014; National Development Council (NDC), 2019; Seattle's Department of Construction and Inspections (SDCI), 2017). Other studies ascribe it to lack of legislation, especially mandatory obligation for seismic strengthening (Nguyen, 2020; Rabinovici, 2012). In particular, the California Seismic Safety Commission (CSSC) tracked the retrofit progress for URM buildings in 104 jurisdictions during the years 1990–2006 and found that jurisdictions that implemented a mandatory strengthening program gained higher retrofit rates compared with those that developed a voluntary program. Yet, voluntary strengthening programs were more effective than the programs that only notified owners that their buildings are potentially hazardous (CSSC, 2006).

Wood-frame soft-story buildings are one of the most hazardous structural types in California. The soft or weak story,[1] typically on the ground floor due to large parking or commercial spaces, cannot provide sufficient lateral support to the stiff and heavy mass of the stories above them during strong earthquake shaking (Applied Technology Council (ATC), 2010). Therefore, an increasing number of cities are taking steps to mitigate seismic risk for this building type. Rabinovici (2012) interviewed 43 property owners, managers, and institution representatives who participated in the soft-story program in Berkeley, CA. The program required property owners to submit evaluation reports, inform tenants of seismic risks, and post warning signs onsite (City of Berkeley, 2005). The author observed that: (1) nearly all owners were unaware of the vulnerability of their buildings before the program; (2) the mandatory screening and disclosure approach effectively transformed individual perspectives and led to voluntary retrofits; (3) the primary motivator for seismic retrofit was economic benefits, but social and individual factors might override economic considerations in some circumstances. Unlike Berkeley, the City of San Francisco (2013) enforced a tight compliance schedule for structural evaluation and seismic upgrades of soft-story buildings. A survey for 101 rental property owners indicated that owner's safety awareness, financial capability, and experience with past earthquakes, as well as housing market conditions and regulatory requirements, affected the adoption of retrofit measures. A small percentage of owners were only motivated by the legal requirement (Nguyen, 2020).

New Zealand is facing the same challenge in motivating owners to take adequate mitigation measures for earthquake-prone buildings (Egbelakin et al., 2008, 2014, 2017). The 2004 Building Act authorized territories to craft earthquake risk mitigation policies, adopting retrofit standards based on their seismicity conditions (Egbelakin, 2013). Egbelakin and Wilkinson (2008) interviewed 20 stakeholders from the territories that implemented a voluntary retrofit policy and found two major concerns that inhibited owners from retrofitting earthquake-prone buildings: whether retrofit cost can be recovered in an acceptable period through increased rents or housing sales, and whether retrofit can provide desirable protection for occupants and properties. However, owners who had earlier experience with an earthquake were more likely to conduct retrofit work and support high seismic performance standards. Public organizations tended to consider a wide range of benefits from the renovation work, including protecting lives, health, and welfare, preserving heritage buildings, reducing the need for displacement and demolition, and providing uninterrupted services. Another study interviewed 48 stakeholders in the City of Auckland, Christchurch, Gisborne, and Wellington, where retrofit was not a mandate for commercial buildings, and suggested that owner's intention for retrofitting commercial buildings was often discouraged by high initial costs, cost uncertainty (e.g. hidden costs), business interruption costs, high seismic performance criteria, and real estate and insurance markets that underestimate or disregard marginal benefits from the strengthening work (Egbelakin et al., 2014).

Table 1 summarizes the economic, social, regulatory, and individual factors that may influence building owner's retrofit decisions, as indicated by the literature. The objectives of this article are to (1) identify primary factors that prompt or prevent commercial and residential property owners from taking retrofit measures, (2) assess to what degree those factors affect risk mitigation through retrofit, and (3) explore potential approaches to promote seismic retrofit in California. This research makes three contributions to the literature on earthquake risk reduction.

- Reveal general rules that govern the retrofit decisions of building owners.

Previous studies relied on a small amount of data collected from surveys or interviews, which may incompletely reflect the perspectives of the entire community due to sample size (Egbelakin et al., 2014; Rabinovici, 2012). Moreover, whether respondents provided accurate and honest answers can affect the reliability of the data and thus the conclusion drawn from it. This research uses public data to analyze all affected buildings, population, and neighborhoods, which allows exploring the general rules that govern decision making for seismic retrofit, rather than predicting individual preferences or behaviors.

- Improve the understanding of the influence of economic, social, regulatory, and individual factors on retrofit compliance.

Various motivators and impediments to retrofit implementation have been documented in the literature, but it is still unclear to what degree these factors can influence retrofit decisions. Among a few studies that sought to quantify the influence, Egbelakin et al. (2017)

Table 1. Factors in the literature influencing building owner's decisions about seismic retrofit

Study		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Economic factors	Retrofit cost	x	x	x	x	x			
	Insurance premium	x		x	x	x			
	Financial capability	x	x		x		x		
	Financial incentive[a]		x	x	x	x			
	Rent/revenue	x	x	x	x	x			
	Property value	x		x	x	x			
	Market condition			x		x			
Social factors	Risk perception	x	x	x	x	x	x	x	x
	Perceived responsibility[b]					x	x	x	x
	Earthquake experience	x	x	x	x	x			x
	Mitigation and preparedness experience	x			x		x	x	x
	Monetary or nonmonetary awards			x		x			
	Observable benefits[c]	x	x			x	x	x	
	Intangible benefits[d]	x							
	Confidence in retrofit techniques	x				x	x		
	Trust in professional engineers	x					x		
Regulatory factors	Mandatory or voluntary compliance	x	x			x			
	Seismic performance criteria			x	x				
	Trigger for retrofit			x	x				
Individual factors	Length of ownership		x						
	Ownership type[e]	x							
	Ownership of multiple properties	x							
	Owner characteristics[f]	x					x	x	x
	Building characteristics[g]	x							x
	Historic building			x					

(1) Rabinovici (2012); (2) Nguyen (2020); (3) Egbelakin and Wilkinson (2008); (4) Egbelakin et al. (2014); (5) Egbelakin et al. (2017); (6) Kashani et al. (2019); (7) Taylen (2015); (8) Albulescu et al. (2021). The "x" means that the factor is identified to influence decisions for seismic retrofit.

[a]Financial incentive options include grants, property tax rebates, fee waivers, low interest rate loans, tax deductibility, subsidies, and tax credits.

[b]Perceived responsibility includes the perceived responsibility of federal and local governments, agencies or organizations, and homeowners.

[c]Observable benefits include improved life and property safety, loss reduction, quick business recovery, and societal loss reduction.

[d]Intangible benefits include reducing worries, avoiding potential guilt or regret in the future, fulfilling a moral duty, and maintaining consistency of ownership.

[e]Ownership types include individual, joint ownership (two or three family members named as co-owners), trust, partnership (a formal corporate entity or investment partnership), university-related institutional (e.g. dormitories, cooperative housing, religious training institutions), and non-university institutional/public/nonprofit (e.g. retirement, affordable housing, motels).

[f]Owner characteristics include age, income, family life (e.g. number of children), community ties, education attainment, career, professional experience (i.e. real estate), attitude and plans about buying, owning, and selling rental properties, and whether the owner lives nearby the property.

[g]Building characteristics include year built, number of stories, size, use or function, and location.

examined the relevance of intrinsic and extrinsic motivators to retrofit intentions and decisions using exploratory factor analysis and confirmatory factor analysis. Taylen (2015) assessed the dependency between retrofit adoption and owner's beliefs and socioeconomic status using the binary logistic regression analysis and path analysis. Albulescu et al. (2021) evaluated the correlation between retrofit implementation and owner's attitudes and experience with hazard preparedness, mitigation, and recovery using the Spearman's rank correlation coefficient and the Mann–Whitney *U* test. Inspired by those studies, this article develops predictive models for retrofit probability, accounting for economic, social, regulatory, and individual factors. This effort would help fill the gap in quantifying the influence of each factor on decision making.

- Provide new insights that can inform future policy and practice of seismic retrofit.

The Cities of Berkeley, San Francisco, and Los Angeles are among the first few cities in California that established a mandatory retrofit program for soft-story buildings (Zhang et al., 2021). Nearby cities followed these practices and developed their retrofit programs (e.g. Oakland, Santa Monica, West Hollywood). However, many cities in high-seismicity regions are observing and assessing other cities' performance before making their policies (e.g. Alameda, Long Beach). The findings of this research can help improve policy making practice of those cities.

The article is organized as follows. Section "Methodology and data" introduces the methods and data employed in this study. Section "Results" presents analysis results, and section "Discussion" discusses the implication of these results for policy development and retrofit implementation. Section "Conclusion" concludes this study and describes future work.

Methodology and data

Methods and experimental design

This study utilizes three seismic retrofit programs in California to illustrate how economic, social, regulatory, and individual factors are likely to influence building owner's retrofit decisions (shown in Table 1).

1. The City of Berkeley initiated a retrofit program for soft-story buildings in 2005. Phase I of the program required building owners to submit an engineering evaluation report that analyzes the capacity of buildings in resisting earthquakes and elaborates the future work needed to remedy identified weaknesses (City of Berkeley, 2005; Rabinovici, 2012). For rental buildings, the owners were required to notify tenants of potential dangers and post an earthquake warning sign at the building entrance. Phase II of the program, which began in 2014, mandated building owners submit screening forms, retrofit plans, and permit applications, and complete retrofit work no later than December 31, 2018 (Angstadt and Roshal, 2013). Buildings that failed to comply with the ordinance would be declared to be public nuisances, and would be repaired, removed, or demolished and/or restricted from use by the city government. There was no requirement for upgrading building sections above the critical story or the floor diaphragm immediately above it.
2. The City of San Francisco passed a soft-story ordinance in 2013, requiring building owners to submit screening forms and optional structural evaluation forms by 15 September 2014. For buildings evaluated as hazardous, owners would be required to submit a permit application with retrofit plans in 1–4 years, and complete retrofit

work in 3–6 years (City of San Francisco, 2013). If owners fail to complete required actions within the time limits, their buildings would be declared as public nuisances, and the city government would vacate, repair, alter, or demolish these buildings. The scope of required work was limited to the ground story and the basement or under property area that has any portion extending above grade. Buildings enrolled in this program were assigned to four compliance tiers based on the building's risk category.

3. The City of Los Angeles (2015) issued two ordinances in 2015 and 2016, respectively, mandating soft-story property owners to apply for retrofit permits in 3.5 years and strengthen the weak story in 7 years. Owners who violate the ordinance would be subject to prosecution and/or administrative enforcement. Buildings were designated to three compliance tiers based on the number of stories and dwelling units. Table 2 summarizes the scopes and requirements of these three retrofit programs.

In this study, the analysis of variance (ANOVA) test is performed to investigate primary factors that influence retrofit implementation for commercial and residential buildings. The analyzed economic factors include median household income, poverty rate, median contract rent, median gross rent (contract rent plus the estimated average monthly cost of utilities), median housing value, and housing vacancy rate at the Census tract level. The social factors comprise population density, educational attainment (high school completion), and health insurance coverage at the Census tract level. The individual factors include building age, number of stories, dwelling units, rooms, property area, lot area, assessed land value, improvement value, fixture value, personal property value, percent of ownership, and length of ownership. Note that, this analysis does not consider all of the influencing factors identified in Table 1 and elsewhere, due to lack of data or difficulty in quantifying those items.

This study further measures the influences of primary factors on retrofit decisions through multilevel regression analysis. Multilevel modeling is a statistical approach that allows parameters to vary across clusters (groups) and nested clusters so as to reduce bias due to ignoring differences among clusters and correlations across clusters. This is achieved by adding random effect terms (i.e. random intercepts and slopes) that are assumed to follow a common distribution (e.g. normal, binomial, or Poisson distribution). This feature enables multilevel modeling to use fewer parameters to model complex relationship, as traditional modeling techniques rely on a set of dummy variables to delineate the difference among groups (Buxton, 2008). Another advantage is that multilevel modeling can increase the accuracy of predictions for clusters that have a limited amount of data because information (i.e. fixed effect) is shared between clusters (Buxton, 2008). The basic multilevel regression model can be written as follows:

$$y_{ij} = \beta_0 + \beta_1 x_{1,ij} + u_{0,j} + u_{1,j} x_{1,ij} + \varepsilon_{ij} \quad (1)$$

where y_{ij} is the outcome variable of cluster j subject i. $x_{1,ij}$ is the predictor of cluster j subject i. β_0 and β_1 are fixed intercept and slope, respectively. $u_{0,j}$ and $u_{1,j}$ are random intercept and slope, respectively, allowing subject i to have a varied intercept and slope. ε_{ij} is the residual. The model can be extended to include multiple predictors and random effects for multiple predictors.

Table 2. Soft-story seismic retrofit programs considered in the experimental design

City	Berkeley	San Francisco	Los Angeles
Ordinance	Ord. 6883-NS Ord. 7360-NS	Ord. 66-13	Ord. 183893 Ord. 184081
Building characteristics	Wood frame, 5 or more dwelling units, constructed before 1978	Wood frame, 3 or more stories and 5 or more dwelling units, constructed before 1978	Wood frame, 2 or more stories and 4 or more dwelling units, constructed before 1978
Performance objective	Collapse prevention in an earthquake with a 5% occurring probability in 50 years	Life safety in an earthquake with a 20% occurring probability in 50 years	75% of the lateral-force-resisting capacity of new construction
Schedule for compliance	**Phase I.** 2005 – 2007 (evaluation) **Phase II.** Jan. 2014—Dec. 2016 (permit application)—Dec. 2018 (retrofit work completion)	**Tier I**[a]. Sep. 2014 (evaluation)—Sep. 2015 (permit application)—Sep. 2017 (retrofit work completion) **Tier II.** Sep. 2014—Sep. 2016—Sep. 2018 **Tier III.** Sep. 2014—Sep. 2017—Sep. 2019 **Tier IV.** Sep. 2014—Sep. 2018—Sep. 2020	**Tier I-1**[b]. May 2016 (evaluation)—Nov. 2019 (permit application)—May 2023 (retrofit work completion) **Tier I-2.** Jul. 2016—Jan. 2020—Jul. 2023 **Tier II.** Oct. 2016—Apr. 2020—Oct. 2023 **Tier III-1.** Jul. 2017—Jan. 2021—Jul. 2024 **Tier III-2.** Aug. 2017—Feb. 2021—Aug. 2024 **Tier III-3.** Sep. 2017—Mar. 2021—Sep. 2024 **Tier III-4.** Nov. 2017—May 2021—Nov. 2024

[a]Buildings in Tier I contain a Group A (assembly), Group E (educational), Group R-2.1, R-3.1, or R-4 (residential) occupancy on any story. Buildings in Tier II have 15 or more dwelling units, except for those assigned to Tier I or IV. Buildings in Tier III do not fall within the definition of another tier. Buildings in Tier IV contain a Group B (business) or Group M (mercantile) occupancy on the first story or in a basement area with any portion extending above grade, or are located in mapped liquefaction zones, except for those assigned to Tier I.

[b]Tier I-1 applies to residential buildings with 3 or more stories and 16 or more dwelling units. Tier I-2 applies to buildings with 2 stories and 16 or more dwelling units. Tier II applies to buildings with 3 or more stories but less than 16 dwelling units. Tiers III-1, III-2, and III-3 apply to buildings with 9–15, 7–8, and 4–6 units, respectively. Tier III-4 applies to condos and commercial buildings.

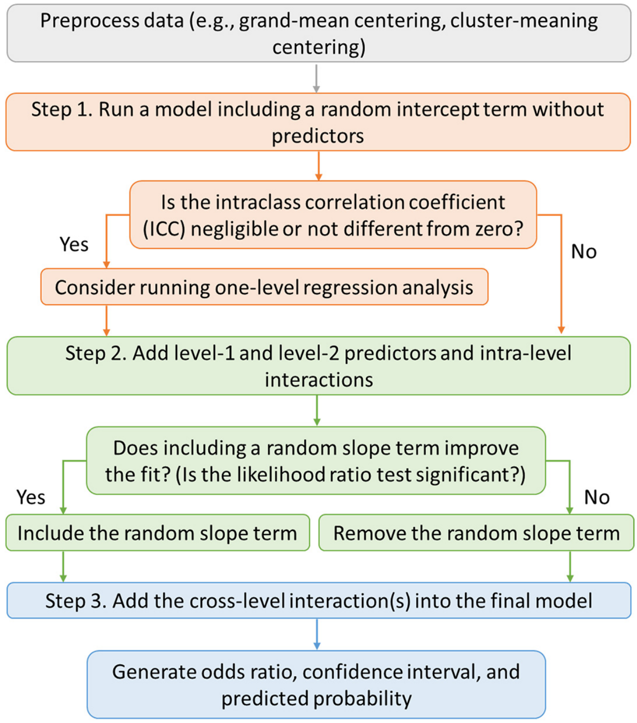

Figure 1. Procedure for multilevel regression analysis.
Source: Adapted from Sommet and Morselli (2017).

In terms of a binary outcome variable, denoted as [0, 1], the following multilevel logistic regression model (MLRM) is used to predict the log odds of the outcome. The *odds* is the probability that the event will occur over the probability that the event will not occur.

$$\ln\left[\frac{P(y_{ij}=1)}{1-P(y_{ij}=1)}\right] = \operatorname{logit}\left[P(y_{ij}=1)\right] = \beta_0 + \beta_1 x_{1,ij} + u_{0,j} + u_{1,j}x_{1,ij} \tag{2}$$

where $P(y_{ij}=1)$ is the probability that the outcome variable y_{ij} equals one, meaning the event will occur.

Figure 1 outlines the procedure employed in this study to create MLRMs for retrofit outcome prediction (i.e. retrofitted and nonretrofitted). In the preliminary phase, centering methods are employed to rescale predictor variables to facilitate better interpretation of some estimates. In particular, the fixed intercept will become the log odds that the outcome variable equals one. Two centering methods are commonly used in multilevel analysis: grand-mean centering and cluster-mean centering (Enders and Tofighi, 2007). The former rescales a predictor variable by subtracting the general mean ($\bar{x}$) of the predictor, while the latter subtracts the individual's group mean ($\bar{x}_j$). It is worth noting that centering only alters intercept and intercept variance and does not affect slope values or the significance test.

Step 1 uses the intraclass correlation coefficient (ICC), ranging from zero to one, to measure to what extent the log odds varies from one group to another. A value of zero means that the outcome does not vary across groups, and the chance that the event will occur is the same for each group. A value of one indicates perfect interdependence between the outcome and groups, meaning that the event will occur in some groups and will not occur in other groups. The ICC is computed as follows:

$$\mathrm{ICC} = \frac{\mathrm{var}\left(u_{0,j}\right)}{\mathrm{var}\left(u_{0j}\right) + (\pi^2/3)} \tag{3}$$

where $\mathrm{var}\left(u_{0,j}\right)$ is the random intercept variance. $(\pi^2/3)$ is the level-1 variance component assuming that the log odds follows the standard logistic distribution.

The likelihood ratio (LR) test performed in step 2 tests the hypothesis that adding the random slope does not improve model performance based on a chi-square test (χ^2). The model that contains a random slope, termed the augmented immediate model (AIM), is compared with the model that does not consider the random slope, termed the constrained immediate model (CIM). If the deviance of the AIM (relative to the observation) is significantly lower than that of the CIM, including the random slope significantly improves the fit and should be kept in the final model. Otherwise, the random term should be discarded to avoid overparameterization. Below is the formula for the likelihood ratio test.

$$\mathrm{LR}\ \chi^2 = \mathrm{deviance(CIM)} - \mathrm{deviance(AIM)} \tag{4}$$

Table 3 describes the model structures employed in the three case studies. A single-level model is adopted for the Berkley's case because the ICC is close to zero, suggesting the outcome does not vary across Census tract groups. A two-level model is adopted for the San Francisco and Los Angeles' cases, where Census tract groups contribute to 5% and 4% of retrofit outcomes, respectively. Predictor variables are examined prior to use to avoid collinearity, singularity, and redundancy because these may cause the model to not converge or converge toward a wrong value. Two categorical variables are included in the model that reflect regulatory impacts on retrofit implementation: retrofit tier and buildings use. Building use is associated with incentive policies and triggers for other compliances.

Level-1 predictors are cluster-mean centered, and level-2 predictors are grand-mean centered, except for categorical variables. Therefore, the coefficients of level-1 predictors only reflect within-group difference, and the coefficients of level-2 predictors only reflect between-group difference. Final MLRMs and validation results are presented in the supplemental material.

Data

The compliance status of Berkeley's soft-story buildings is monitored by the Building and Safety Division. The data updated on January 11, 2021, indicates that 77% of 355 buildings completed retrofit work, 17% of buildings were undergoing seismic upgrades, and 6% of buildings were out of compliance (City of Berkeley, 2021). This study uses data published on October 16, 2015 (City of Berkeley, 2015) to analyze retrofit decisions of building owners in Berkeley during Phase I, as later detailed documentation for the compliance status is not available. The data show that the soft-story inventory consisted of 308 properties, in which 92% were multifamily residential buildings (Table 4). About 53% of the buildings

Table 3. Group levels and predictor variables in multilevel logistic regression models (MLRMs)

Predictor	Berkeley	San Francisco	Los Angeles
Retrofit tier		1	1
Building use	1	1	1
Building age	1	1	1
Number of stories	1	1	
Number of rooms		1	
Number of bedrooms			1
Property area			1
Lot area	1		
Assessed land value	1	1	1
Median gross rent	1	2	
Median housing value	1	2	2
Vacancy rate	1	2	2
Population density	1	2	2
Educational attainment	1	2	2
Health insurance coverage		2	2

The "1" denotes the level-1 predictor, and "2" denotes the level-2 predictor, which is grouped by Census tracts.

Table 4. Retrofit rate for soft-story buildings in Berkeley (number of retrofitted buildings/total identified number)

Phase	Number of buildings	Retrofit rate	Retrofit rate by building use*		
			Commercial	Single-family residential	Multifamily residential
I	308	53.2%	32% (6/19)	67% (2/3)	57% (147/256)
II (Total)	355	76.9%	53% (10/19)	75% (3/4)	81% (235/290)

Phase II added 47 soft-story buildings to the inventory. The rest of buildings are consistent with Phase I.
*The use categories of 30 buildings in Phase I and 42 buildings in Phase II are unknown.

were retrofitted in Phase I and met the criteria of removal from the inventory. Assessor's data and real estate data are obtained from the Almeda County Open Data (2020) and ATTOM^{TM} database (2021).

The City of San Francisco offers a weekly update for the compliance status of soft-story buildings on the Open Data portal (DataSF, 2020). This study uses the data published on September 25, 2020, which is 10 days after the deadline for the last compliance tier. The data show that multifamily residential buildings constituted the largest proportion of the soft-story inventory, followed by single-family residential, commercial hotel, commercial miscellaneous, and commercial retail buildings (Table 5). About 76% of soft-story buildings were retrofitted to meet the requirements of the ordinance within the compliance period. Assessor's data are obtained from DataSF (2020) and ATTOM^{TM} database (2021).

The soft-story inventory of Los Angeles is maintained by the Department of Building and Safety and can be accessed upon request. The inventory created on July 6, 2020, contained 22,281 properties, in which 54% were apartments and 46% were condos. The Department also updates building permits data for soft-story apartments every week (Los Angeles Department of Building and Safety (LADBS), 2021). The data published on

Table 5. Retrofit rate for soft-story buildings in San Francisco (number of retrofitted buildings/total identified number)

Tier	Number of buildings	Retrofit rate	Retrofit rate by building use*				
			Commercial miscellaneous	Commercial hotel	Commercial retail	Single-family residential	Multifamily residential
I	7	71.4%	0 (0/1)	50% (1/2)	N/A	N/A	100% (2/2)
II	515	86.0%	100% (2/2)	36% (5/14)	N/A	100% (9/9)	86% (369/427)
III	3383	80.1%	100% (6/6)	67% (10/15)	100% (2/2)	93% (114/123)	80% (2,259/2,838)
IV	1025	59.1%	58% (19/33)	50% (24/48)	75% (3/4)	83% (10/12)	61% (436/713)
Total	4930	76.3%	64.3% (27/42)	50.6% (40/79)	83.3% (5/6)	92.4% (133/144)	77.0% (3,066/3,980)

N/A: not applicable.
*The use categories of 679 buildings are unknown.

Table 6. Retrofit rate for soft-story apartments in Los Angeles (number of retrofitted buildings/total identified number)

Tier	Number of buildings	Retrofit rate	Retrofit rate by building use	
			Mixed-use commercial*	Multifamily residential
I-1	1271	60.1%	75% (3/4)	60% (761/1267)
I-2	1375	62.5%	57% (8/14)	63% (852/1361)
II	1364	66.3%	79% (22/28)	66% (883/1336)
III-1	3486	36.3%	9% (2/22)	36% (1263/3464)
III-2	2365	35.2%	5% (1/21)	35% (832/2344)
III-3	2179	34.6%	29% (64/220)	35% (691/1959)
Total	12,040	44.7%	32% (100/309)	53% (5282/11,731)

Condos and a few commercial buildings are designated to Tier III-4, which is not analyzed in this study.
*Mixed-used commercial buildings have commercial space on the ground floor and apartment units on the top floor.

February 22, 2021, which are used in this study, show that about 75% of apartments received a permit, and 45% of apartments complied with the ordinance (Table 6). Assessor's data are derived from the Los Angeles County Open Data (2021).

The socioeconomic data, including median household income, median gross rent, median housing value, vacancy rate, population density, education attainment, and health insurance coverage rate, are obtained from the National Historical Geographic Information System (NHGIS), which provides free online access to summary statistics and GIS files for US Census surveys and other national surveys (Manson et al., 2020). The Census 2015–2019 American Community Survey data at Census tract level are used in this study. All values are adjusted to the 2019 US dollars. Summary statistics of soft-story buildings and a comparison of retrofitted and nonretrofitted buildings are presented in the supplemental material.

Results

Primary factors influencing retrofit implementation

The ANOVA test results suggest there are statistical differences between retrofitted and nonretrofitted buildings with respect to economic, social, and individual factors. For commercial buildings (commercial miscellaneous, hotels, and retails), the difference is significant in the number of stories and rooms, land value, vacancy rate, and population density of the neighborhood ($p < .05$). Median household income and poverty rate may slightly affect retrofit adoption ($p < .1$). For mixed-use commercial buildings, the difference is also significant in building age, median gross rent or median contract rent, educational attainment, and health insurance coverage ($p < .05$).

Decisions for retrofitting single-family residential buildings (i.e. condos) can be strongly associated with the number of residential units and improvement value ($p < .05$), and slightly associated with number of stories, land value, median household income, poverty rate, and median housing value ($p < .1$). For multifamily residential buildings (i.e. apartments), retrofit may be dependent upon factors such as building age, number of rooms, property area or lot area, land value, median housing value, median gross rent or median contract rent, poverty rate, educational attainment, and health insurance coverage in the neighborhood ($p < .05$). The mean differences between retrofitted and nonretrofitted

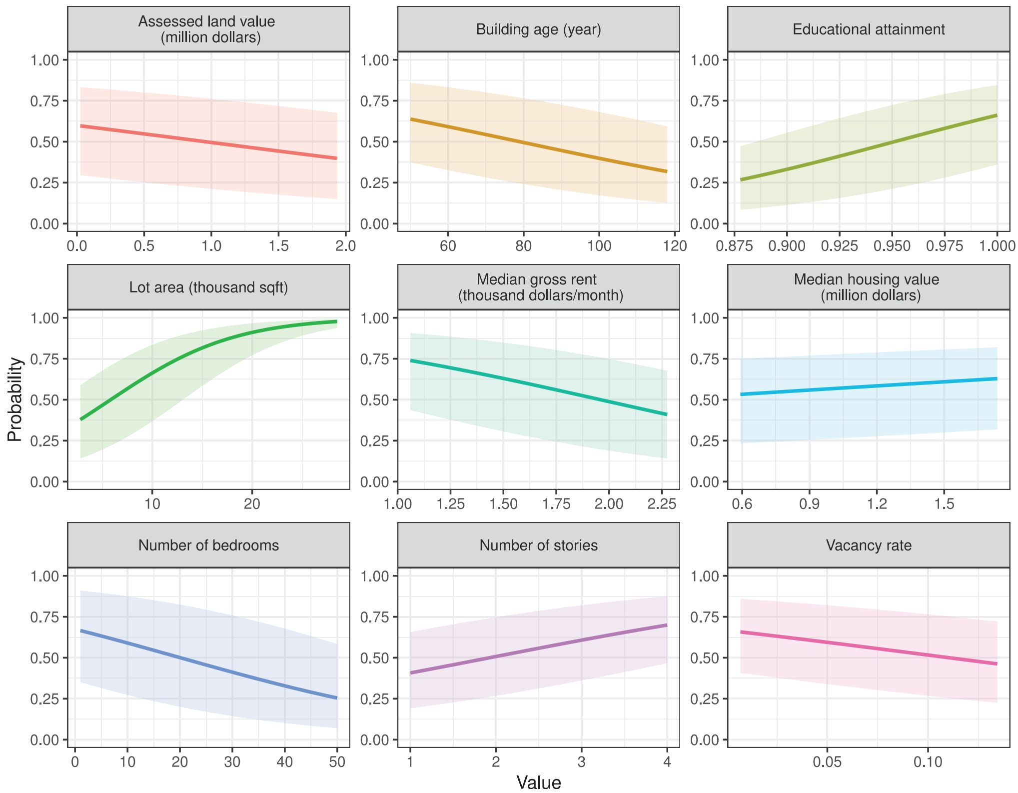

Figure 2. Retrofit probability as a function of predictor variables for Berkeley's soft-story buildings. The central line represents the mean probability; the shaded area represents the 95% confidence interval.

buildings are presented in the supplemental material. It should be noted that other factors not included in this analysis may also have high relevance for retrofit decisions.

Influences of economic, social, regulatory, and individual factors

Three MLRMs are developed to predict the retrofit probability of soft-story buildings in each of the three case study cities. When calculated for a single building, the retrofit probability indicates likelihood of an individual owner's decision to retrofit. When calculated for a group of buildings, the retrofit probability depicts the percent of owners likely to conduct retrofit work. This study focuses on the latter as individual decisions are highly idiosyncratic, and modeling decisions at the individual level requires data on personal beliefs and social context, as discussed in the later section.

Figures 2 to 4 display the retrofit probability as a function of predictor variables considering fixed effects only. All else equal, the retrofit probability in San Francisco is higher than that of Berkeley and Los Angeles because its data contain more retrofit cases (76.3%) than the other two (56.0% and 44.7%). See Tables 4 to 6 for details. Note that, the group-level retrofit probability is affected by the initial population structure (i.e. percent of

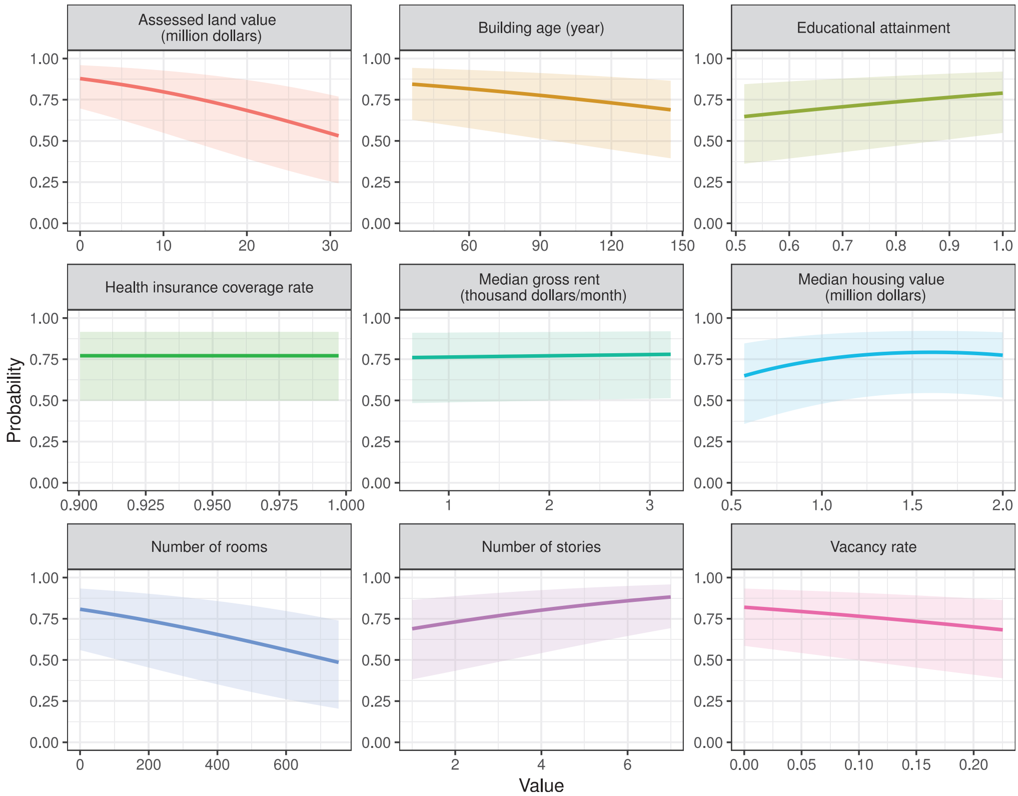

Figure 3. Retrofit probability as a function of predictor variables for San Francisco's soft-story buildings. The central line represents the mean probability; the shaded area represents the 95% confidence interval.

retrofit and nonretrofit), but the degree of increase or decrease in the probability is independent of the population structure.

The regression analysis results suggest that retrofit probability may increase with building height (number of stories), property area, median housing value, population density, high school completion rate (educational attainment), and health insurance coverage rate. In Berkeley, the probability that a four-story building is retrofitted is, *ceteris paribus*, 0.3 higher than that of a one-story building. The mean likelihood of retrofit may rise by 0.4 as the high school completion rate increases from 87% to 100% and grow by 0.1 as median housing value increases from $ 0.6 million to $1.7 million. In San Francisco, the probability that a seven-story building is retrofitted is, *ceteris paribus*, 0.2 higher than that of a one-story building. The mean likelihood may increase by 0.1 as median housing value increases from $ 0.6 million to $2.0 million or as health insurance coverage rate increases from 90% to 100%. In Los Angeles, the mean likelihood of retrofit may grow by 0.08 as median housing value increases from $ 0.2 million to $2.0 million or as high school completion rate increases from 32% to 100%.

The results also indicate that the retrofit probability may decrease with increasing building age, number of rooms, land value, and vacancy rate. In Berkeley, the mean

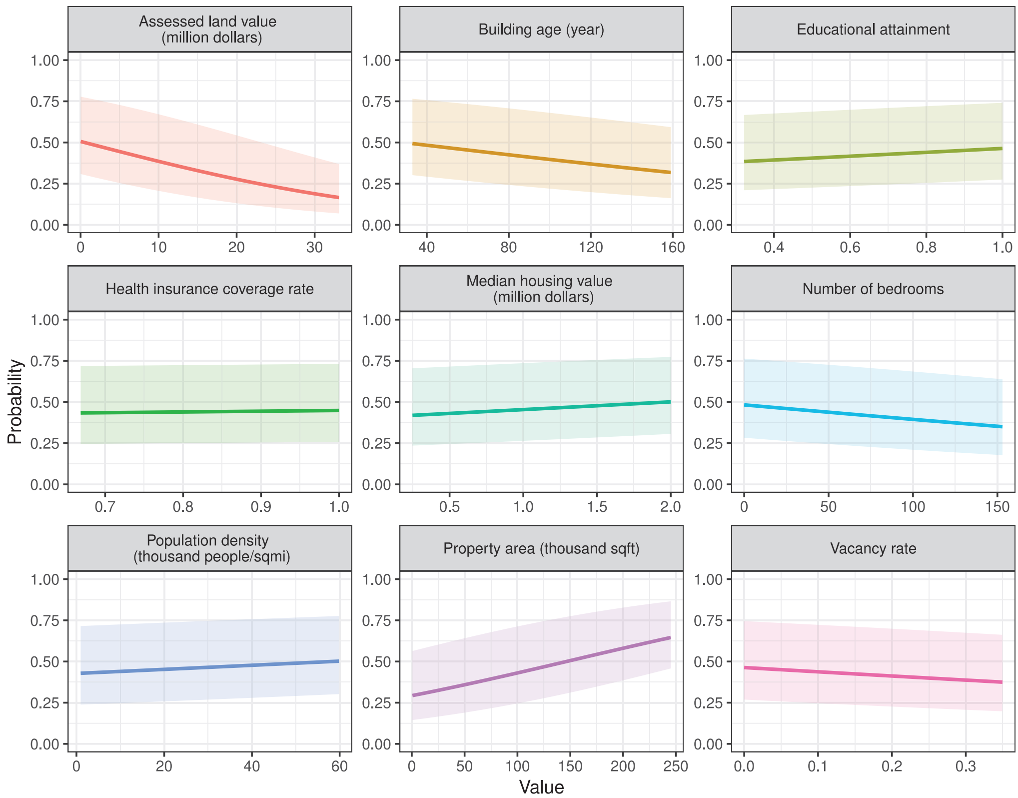

Figure 4. Retrofit probability as a function of predictor variables for Los Angeles' soft-story buildings. The central line represents the mean probability; the shaded area represents the 95% confidence interval.

likelihood may decline by 0.3 as building age increases from 50 to 118 years and drop by 0.2 as vacancy rate increases from 6% to 13%. The probability that a building with one room is retrofitted is, *ceteris paribus*, 0.4 higher than that of a building with 50 rooms. In San Francisco, the mean likelihood may decline by 0.15 as building age increases from 36 to 145 years and drop by 0.14 as vacancy rate increases from 0% to 23%. In Los Angeles, the mean likelihood may decrease by 0.18 as building age increases from 33 to 159 years and decline by 0.34 as land value increases from $ 0.01 million to $33.1 million.

Furthermore, retrofit probability can be positively or negatively associated with median gross rent. In Berkeley, the mean likelihood of retrofit may drop by 0.46 as the median gross rent increases from $1060 to $2275 per month. However, in San Francisco and Los Angeles, retrofit probability may slightly increase with median gross rent. The variables improvement value, median contract rent, poverty rate, and median household income are not included in MLRMs because they are highly correlated with other variables.

Figure 5 shows the odds ratio associated with each predictor, computed by exponentializing the regression coefficients and confidence intervals of the MLRM. For numerical variables, the odds ratio depicts the change of retrofit probability over nonretrofit probability for a one unit increase of the predictor. This change is not constant but in an

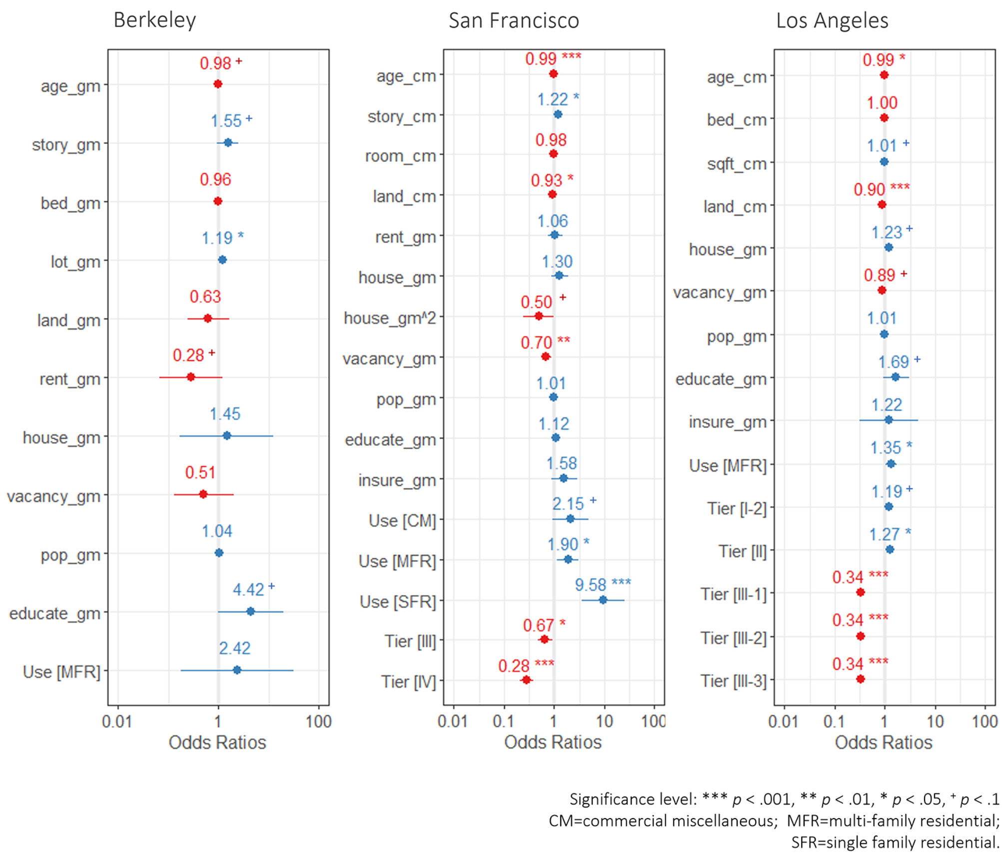

Figure 5. Fixed effects of predictor variables. The central point represents the mean value; the extended line represents the 95% confidence interval. The appended "cm" and "gm" denote cluster-mean centering and grand-mean centering, respectively. Variables: age (building age), story (number of stories), bed (number of bedrooms), room (number of rooms), sqft (property area), lot (lot area), land (assessed land value), rent (median gross rent), house (median housing value), house^2 (square of median housing value), vacancy (vacancy rate), pop (population density), insure (health insurance coverage rate), educate (high school completion rate), income (median household income), Use [use type] (building use), and Tier [tier number] (retrofit tier).

exponential manner. An odds ratio above one means that retrofit probability is greater than nonretrofit probability, and the predictor has a positive impact on retrofit adoption. In contrast, an odds ratio below one indicates a negative impact. For categorical variables (i.e. building use and retrofit tier), the odds ratio describes the change of retrofit probability over nonretrofit probability when one category is replaced by another. This change is influenced by the selected baseline.

As can be seen in Figure 5, multifamily residential buildings are more likely to be strengthened compared with commercial buildings (the baseline) in Berkeley and Los Angeles. In San Francisco, single-family residential buildings (i.e. condos) are most likely to comply with ordinance requirements, followed by multifamily residential buildings (i.e. apartments), commercial miscellaneous, relative to commercial hotels (the baseline). Moreover, retrofit tier greatly affects compliance status ($p < .01$). In San Francisco, buildings in later tiers III and IV are less likely to be retrofitted than the earlier tier II (the baseline). In Los Angeles, buildings in later tier III are also less likely to be retrofitted than earlier tiers I-2 and II, but the earliest tier I-1 (the baseline) has a lower compliance rate compared with subsequent tier I-2. The single-family residential use in Berkeley and commercial retail use and retrofit tier I in San Francisco are not modeled because of very small sample sizes. The random effect that reflects the difference among 695 Census tract groups in Los Angeles is discussed in the supplemental material.

Discussion

This section discusses the potential mechanisms through which individual, economic, social, and regulatory factors influence the likelihood of building owners to undertake seismic risk mitigation through retrofit, and provides potential solutions for California to promote compliance with seismic retrofit ordinances.

The influence of individual factors on retrofit implementation

Building age. Year built is an important indicator for the overall seismic performance of a building. Older buildings are more likely to possess critical structural deficiencies, making them particularly susceptible to earthquake damage. These deficiencies are ameliorated in newer construction as new techniques are introduced (e.g. plywood structural sheathing panels, oriented strand boards, rod hold-down systems), and as seismic codes and standards are regularly improved over time[2] (Sutley and Van de Lindt, 2016). Therefore, older buildings may require more strengthening efforts compared with younger buildings so as to meet seismic performance requirements. The incurred higher retrofit costs and difficulty (Fung et al., 2020; Rabinovici, 2012) may hinder owners from adopting retrofit solutions. Moreover, potential losses to younger properties are likely more substantial to building owners as the building still has a long useable life and the owner is likely still paying off a mortgage or commercial real estate loan. This may motivate owners to take retrofit measures to protect younger buildings. All these agree with the results of this study that showing that the retrofit probability declines as building age increases.

Building age also negatively affects rental prices and house values because older buildings are often equipped with old amenities, inferior finishes, and out-of-date designs, making them less attractive and competitive. RentHop (2017) reported that in New York City, one-bedroom apartments tend to be cheaper by around $6 per year of age, and pre-1942 apartments are on average 10%–12% cheaper than their newer counterparts. These relatively low rent prices and house values may make it difficult for owners to recover retrofit costs through rent collection and housing sales. This may explain why the retrofit decision for apartments is highly correlated with building age.

Building height and size. Building height and size are indicators for the risk associated with structural failure. The collapse of a tall, large building can cause a larger number of casualties and injuries compared with a short, small one. This may provide an explanation for the results of this study that the retrofit probability increases with the number of stories and property area. In Berkeley, buildings with large lots were voluntarily retrofitted, likely due to owner's high awareness of risk (Rabinovici, 2012). However, number of rooms may decrease the retrofit probability for two reasons. First, more rooms require more strengthening efforts and result in higher retrofit costs (Fung et al., 2020). Second, managing and coordinating the retrofit project in a building with many households is complex and time-consuming. Soft-story apartments typically do not require displacement of tenants as the retrofit scope is limited to the ground-floor garages, but this increases construction logistics because of the need to work around existing tenants, minimize noise and dust, and avoid blocking circulation or access.

The influence of economic factors on retrofit implementation

Property value. In this study, three variables are pertinent to property value: assessed land value, assessed improvement value, and median housing value of the neighborhood. The results show that high land values can discourage seismic retrofit in the community, but a high median housing value can promote it. High-density residential and commercial buildings are typically built on high-value land because developers normally respond to the increase in land price by providing more space per land unit and building taller (Ahlfeldt and McMillen, 2018). This agrees with the data used in this study, for which land value is highly correlated with improvement value of the building and positively associated with the number of stories, number of units, and property area, which all point to high-density residential or commercial use. The likely reasons that high land values lead to low retrofit probabilities include greater concerns for business disruption and loss of revenue during seismic rehabilitation and greater motivation for reconstruction if higher land values for these properties were paired with relatively low improvement values.

Median housing values provide a general picture of the property market condition in a region. A favorable market features a rising average home sale price and a growing total sale number. In terms of seismic retrofit, a favorable market should value the economic benefit of reduced seismic risks and force down the property value of similar, nonretrofitted buildings (Egbelakin and Wilkinson, 2011). In the United States, some online real estate marketplaces (e.g. Zillow) have included seismic retrofit-related activities in home descriptions, which may contribute to increased resale values (Alhumaidi, 2020). However, seismic retrofit is often depicted by obscure words like foundation strengthening, and there is not a score in the marketplace that highlights retrofit implementation (e.g. like the Sun Number™ that indicates solar energy deployment). These collectively may lead to an underestimation of the value of seismic retrofit (Alhumaidi, 2020). Since protecting property investments is an important motivation for building owners (Rabinovici, 2012), the results of this study suggest that a high median housing value may be correlated with additional investments to secure the expected returns from properties. Indeed, the literature has indicated that owners who bought properties as long-term investments are more likely to do strengthening work to protect property values (Nguyen, 2020; Rabinovici, 2012).

Rent price and vacancy rate. This study uses rent and vacancy data aggregated to the Census tract level, which can lead to an underestimation (or overestimation) of individual-level dependency if a particular building is more (or less) sensitive to rent price and vacancy rate compared with an average soft-story building. The results show that a low median rent or a high vacancy rate can discourage seismic retrofit in the community. This is because rent and vacancy rate directly affect the revenue of apartments and thus the ability of owners to invest in seismic renovation projects. In addition, high vacancy rates can reduce the benefits of retrofit by reducing expected rents for the retrofitted building. However, in Berkeley, a high median rent may impede owners from retrofitting, likely due to the difficulty in recouping retrofit costs, because increasing rent prices may cause tenants to move to other apartments that do not need a retrofit.

The influence of social factors on retrofit implementation

Educational attainment. Education can enhance individual cognitive and learning skills, as well as access to information, which collectively can improve disaster preparedness at individual, household, and community levels (Muttarak and Pothisiri, 2013). Disaster-related education, with objectives to enhance risk perception, critical awareness, perceived responsibility, outcome expectancy, and self-efficacy of community members, is crucial to successful implementation of retrofit policies (Egbelakin et al., 2011; Kashani et al., 2019; Taylan, 2015). Risk perception is an individual judgment about the frequency and severity of a hazard event. Critical awareness is an active, persistent, and careful consideration for the importance and urgency of taking risk mitigation measures. Perceived responsibility is the self-attribution of responsibility in minimizing the effects of natural hazards. Outcome expectancy is the belief in the effectiveness of retrofit interventions, while self-efficacy is the belief in one's ability to implement a retrofit. Literature indicated that building owners possessing the above traits tend to undertake retrofit measures in a voluntary manner (Kashani et al., 2019; Taylan, 2015). Tenants with higher earthquake risk perception may stipulate owners reduce potential risks (Rabinovici, 2012). In contrast, owners with a low sense of responsibility may rely on the government to protect their lives and properties (Lindell and Whitney, 2000; Taylan, 2015). Owners who are doubtful of seismic risks, retrofit outcomes, or their capabilities may hesitate to conduct rehabilitation work (Kashani et al., 2019; Taylan, 2015). Finally, tenants' low awareness of seismic hazards may discourage owners to invest on retrofit measures (Rabinovici, 2012). Consistent with these findings in the literature, the regression analysis in this study also shows that the retrofit probability is positively associated with education level.

Population density. The regression analysis in this study suggests a weak positive association between retrofit probability and population density. This is likely because soft-story buildings are concentrated in high-density neighborhoods and tend to house a significant number of people in those neighborhoods (ATC, 2010). In San Francisco, the five neighborhoods with the highest concentration of soft-story buildings contain more than 70% of people living in soft-story buildings, which makes seismic retrofits imperative (ATC, 2010). However, the weak association indicates that population density is not as influential as other factors in motivating seismic retrofits.

The influence of regulatory factors on retrofit implementation

Building use. The retrofit probability of commercial buildings (hotels, retail, mixed use, and other) is lower than that of residential buildings (condos and apartments) computed based on the available data of the three soft-story programs. There are three main reasons. First, unlike apartment buildings that can recoup retrofit expenses from cost recovery programs, commercial hotels and retail have to seek other solutions, such as increasing sales and reducing operating costs. In particular, San Francisco allowed apartment owners to pass the full amount to tenants over 20 years. Los Angeles allowed up to 50% of retrofit costs to be shared with tenants on a 10-year basis. A survey conducted in San Francisco suggests that the cost recovery program motivated many apartment owners to do seismic renovation work (Nguyen, 2020). Second, commercial buildings need to relocate businesses in the ground story during seismic rehabilitation, which incurs displacement and business interruption costs. Third, commercial renovation can trigger other renovation requirements to bring buildings into compliance with modern codes and standards, such as Americans with Disabilities Act (ADA) compliance,[3] which increases retrofit expense and difficulty. In Berkeley, Phase I of the retrofit program focused on residential buildings (mandatory notification and voluntary retrofit) whereas commercial buildings were voluntary to comply, which may also affect retrofit probabilities.

Retrofit tier. Local ordinances have proven to be the most effective approach to promote seismic retrofits (CSSC, 1995, 2006; NDC, 2019; PBEM, 2017; Rabinovici, 2012). Los Angeles incorporated mandatory retrofit requirements into the soft-story ordinance in 2015 as the voluntary ordinance enacted since 1998 only led to a few retrofits. Berkeley made seismic upgrades obligatory in 2014 even though its soft-story program achieved a great deal of voluntary retrofits over the preceding 10 years. The Cities of Seattle, WA, and Portland, OR, are seeking appropriate strategies to mandate structural reinforcements for URM buildings as existing voluntary policies are not effective enough (NDC, 2019; PBEM, 2017). Furthermore, New Zealand took lessons from the 2011 Christchurch Earthquake and required territorial authorities to identify earthquake-prone buildings and to enforce a tight compliance schedule for seismic upgrades in 2016 (Filippova and Noy, 2020). These are consistent with the results of this study, indicating that regulatory factor (i.e. retrofit tier) played a significant role in shaping owner's retrofit decisions ($p < .01$). In particular, higher priority tiers show more positive impacts while lower priority tiers exhibit more negative impacts on retrofit actions relative to the baseline, implying that the tier approach might help the cities effectively allocate resources (e.g. plan review, permit issuance, technical assistance) to buildings at high risk.

It is common for city governments to extend the deadline until full compliance is reached (NDC, 2019). Berkeley and San Francisco are monitoring the compliance status of remaining buildings, providing deadline extensions for owners claiming financial difficulty, and regularly publishing updated soft-story inventories (City of Berkeley, 2021; DataSF, 2020). Two major reasons for the delay, as indicated by literature, are weak enforcement and insufficient financial incentives (NDC, 2019). Notably, Nguyen (2020) pointed out that San Francisco's cost recovery program does not apply to low-income communities and does not help with high upfront costs. In addition, Englander (2018) urged the Los Angeles city council to provide upfront financial assistance for property owners. Availability of financial support can help to ensure that retrofit measures also benefit disadvantaged and marginalized populations.

Potential solutions for California

The results and preceding discussion suggest multiple ways that communities in California may promote implementation of seismic retrofits, with particular attention to the differences between residential and commercial buildings:

1. **Retrofit costs:** It is important to remember how retrofit cost varies across residential and commercial buildings; in particular, older, taller, and larger buildings tend to be more expensive, and the retrofit cost does not necessarily increase proportionately with size or age. Investing in developing inexpensive retrofit methods,

especially for older, taller, and larger buildings, could help reduce financial burdens of owners and encourage the adoption of retrofit measures.

2. **Market conditions:** Building owners may not be aware of the risk their buildings face in the event of an earthquake, nor is there readily available information on the impact of earthquake risk reduction on property values. Including earthquake risk assessment in property valuation processes and requiring mandatory disclosure of a building's seismic risk in the property market transaction could help convince owners to invest in seismic retrofits.
3. **Education and outreach:** If building owners are unaware of the risk to their properties, it is unlikely that tenants and other stakeholders in the community are aware of the potential risks from earthquakes to the buildings they use. Improving community awareness of building safety and sharing knowledge of disaster preparedness, through educational programs could help create a safe and resilient community. Research has shown that disaster-related education can change mitigation behaviors by enhancing risk perception, critical awareness, perceived responsibility, outcome expectancy, and self-efficacy.
4. **Enforcement:** The experiences of Los Angeles and San Francisco suggest that prioritizing buildings for retrofit and separating compliance into different tiers achieved relatively higher implementation for buildings in the high-priority tiers. However, compliance rate might not reach 100% even under mandatory ordinances. Continually enforcing ordinances until full compliance could help enhance effectiveness of retrofit policies and minimize earthquake impacts on residents.
5. **Financial support and incentives:** The results of this article demonstrate that neighborhood economic and sociodemographic characteristics such as median housing values and vacancy rates are good predictors of retrofit probability. This may be because of the differences in opportunity costs faced by building owners in different neighborhoods; for example, high vacancy rates indicate tenants may be able to move more easily to a building that does not require a retrofit, thus limiting opportunities for the building owner to recover retrofit costs. Moreover, owners may perceive that potential business interruption losses outweigh the upfront retrofit cost. Thus, providing financial support and incentives to address high upfront costs and business interruption losses during retrofit, as well as technical assistance could help promote seismic retrofits for commercial and residential buildings, particularly in disadvantaged and marginalized communities. Retrofit programs could consider dedicating a specific proportion of resources and target outreach to address equity concerns.

Conclusion

A significant proportion of buildings were built prior to the implementation of modern codes and standards targeting the prevention of injury and preservation of lives. Yet, it is challenging to motivate property owners to adequately retrofit seismically deficient buildings. In California, many cities and counties have initiated risk mitigation programs for one or more building types. However, to reach a 100% compliance rate it usually takes more time and public resources than initially planned. The results of the present study suggest that mandatory ordinances can greatly motivate owners to strengthen buildings, but a holistic approach that targets solutions to mitigate economic, social, regulatory, and individual impeding factors is required to achieve maximum effectiveness.

The results of this study also suggest that seismic retrofit is less likely to be taken for older, larger residential buildings that are located on higher value land, and less likely to be taken in communities with lower median housing values, lower population densities, lower level of educational attainment, and higher vacancy rates. This implies that the success or failure of retrofit programs is strongly linked to social equity concerns. While many cities already simultaneously plan for or take into account social equity concerns alongside retrofit strategies (e.g. rent increase limits, relocation subsidies for tenants, financial assistance for property owners), many more should also develop this capability. Though this study reveals that social equity could be an important driver of retrofit compliance, a more careful analysis for the role of social equity should be performed to ascertain this.

Moreover, the results show that there are different motivators and impediments to owner's retrofit actions for commercial and residential buildings, which should be considered when promoting retrofits. Since soft-story buildings are largely used for residential purposes in the three case study cities, the assessment for the influence of economic, social, and individual factors is limited to residential buildings. Future research could evaluate retrofit programs for other structural types (e.g. nonductile and tilt-up concrete structures, steel moment frames), which may involve industrial, office, retail and wholesale buildings, and engage different types of owners.

Note that the factors analyzed in this study are a subset of the diverse factors that influence retrofit implementation. Future research could evaluate the roles of the following factors in motivating or impeding the adoption of mitigation measures:[4]

- Capability of local building jurisdictions and city governments to develop and enforce programs and regulations.
- Consequences and penalties for noncompliance (e.g. red tag).
- Availability of original design documents for structural evaluation, well-trained engineers and contractors, financial support, cost-effective retrofit methods, and quality materials.
- Seismic performance requirements for retrofitted buildings (e.g. damage reduction, business continuity).
- Characteristics of building owners and other stakeholders that influence retrofit decision making; particularly to inform development of solutions that can ameliorate social inequities.
- Local and regional conditions: economic (e.g. boom versus recession, prevailing interest rates), population characteristics, and local politics and public sentiment (e.g. attitudes about governmental programs).

Seismically upgrading older buildings is favorable to community resilience and homelessness prevention. However, there may be an argument that it is more favorable to replace older buildings with buildings designed to modern codes as new buildings would perform better during an earthquake than retrofitted ones. Given constraints of economic feasibility and potential displacement, as well as more intensive resource use and pollution from demolition and construction, retrofits are often a preferable option for earthquake risk reduction. This study is limited to insights on the factors that improve success toward the stated goal of the ordinances, which is to enhance life safety, as measured by compliance. We leave the question of whether retrofits improve community resilience for future research.

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Supplemental material

Supplemental material for this article is available online.

Notes

1. Per ASCE 41-17, a weak story is present when the sum of the shear strengths of the seismic-force-resisting system in any story in each direction is less than 80% of the strength in the adjacent story above. A soft story is present when the stiffness of any story is less than 70% of the seismic-force resisting system stiffness of the adjacent story above or less than 80% of the average seismic-force resisting system stiffness of the three stories above.
2. Note that change in building codes has limited impacts on the seismic performance of older apartment buildings because engineering design was not prevalent until the enactment of the 1978 National Earthquake Hazards Reduction Program (NEHRP) provisions. Conventional light framing rules were used for many older apartment buildings.
3. The California Building Code requires that commercial property owners make accessibility improvement whenever they do construction or renovation work, typically under a building permit. In San Francisco, owner's obligation to enhance accessibility is capped at 20% of total construction costs for small projects under the valuation threshold (currently $147,863). This means that commercial property owners may spend 20% more money for seismic retrofits. Moreover, it is difficult to hire qualified ADA specialists who are willing to work on small projects (Dal Pino and Enright, 2019).
4. The authors thank an anonymous referee for these suggestions.

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