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Promoting Earthquake Risk Reduction for Wood-Frame Soft-Story Buildings: A Case Study of San Francisco's Seismic Retrofit Program

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ABSTRACT

Wood-frame soft-story buildings have been responsible for massive loss of life and property in past earthquakes. To reduce future earthquake losses, several cities in California passed ordinances that mandated seismic upgrades for buildings containing weak first stories. However, even with mandates, compliance with the ordinances has been less than complete, with implementation for commercial buildings as low as 50%. This study assesses the effectiveness of the mandatory approach employed by the City of San Francisco and the influence of individual, economic, and social factors on retrofit implementation. A two-level regression model is developed to predict retrofit probability for soft-story buildings. The results indicate that seismic retrofit is less likely to be taken for older, larger buildings that are located on higher-value land, and less likely to be taken in communities with lower median housing values, lower median gross rents, higher vacancy rates, lower population densities, and lower level of educational attainment. However, mandatory retrofit requirements may greatly motivate owners to strengthen buildings that are less desirable due to building characteristics or neighborhood socioeconomic conditions.

Introduction

The vulnerability of wood-frame soft-story buildings was brought to public attention after both the 1989 Loma Prieta Earthquake and the 1994 Northridge Earthquake. Following the two earthquakes, significant improvements were made to seismic provisions for new wood-frame structures. These also encouraged the development of seismic retrofit standards for existing wood-frame buildings and subsequent retrofit programs.

The City and County of San Francisco is the first jurisdiction in California that adopted a mandatory retrofit ordinance for soft-story buildings. The ordinance, passed in 2013, required building owners to submit a permit application with retrofit plans within one to four years and complete retrofit work within three to six years [1]. The ordinance defined four retrofit tiers based on building risk category and provided a staggered timeline for compliance. Tier I includes assembly, eductional, and large residential buildings. Tier II includes residential buildings with 15 or more dwelling units while Tier III has less units. Tier IV buildings typically contain business or mercantile occupancies on the first story or in a basement area. The last tier (Tier IV), which was required to complete retrofit work by

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September 15, 2020, was given one more year to comply so as to reduce interruption to already struggling small businesses during the COVID-19 pandemic. The soft-story inventory released on September 25, 2020 [2] showed that 76.3% of 4,930 soft-story buildings in San Francisco complied with ordinance requirements. This included five buildings in Tier I, 86.0% of 515 buildings in Tier II, 80.1% of 3,383 buildings in Tier III, and 59.1% of 1,025 buildings in Tier IV. In terms of building use, the highest compliance rate appeared in single family residential (92.4%), followed by retail (83.3%), multifamily residential (77.0%), commercial miscellaneous (64.3%), and hotels (50.6%).

In addition to San Francisco, eight cities in California have established a mandatory strengthening program for soft-story buildings [3]. However, past experiences demonstrate that even with mandatory requirements, compliance may not reach 100% [4] because many other factors can influence retrofit implementation, such as retrofit costs, financial incentives, market conditions, risk perception, observable and intangible benefits, and business interruption and relocation [5]. Prior studies have documented a range of factors but it is unclear to what degree these factors influence retrofit implementation [5]. This study evaluates the influence of these factors on compliance by developing a predictive model for retrofit probability using the data for San Francisco's soft-story program.

Methodology

An analysis of variance (ANOVA) test is performed to select factors that differ significantly between retrofitted and non-retrofitted buildings. The candidate factors include (1) individual factors: building age, number of stories, dwelling units, and rooms, property area, lot area, assessed land value, improvement value, fixture value, personal property value, percent of ownership, length of ownership; (2) economic factors: median household income, poverty rate, median contract rent, median gross rent, median housing value, housing vacancy rate at Census tract level; and (3) social factors: population density, educational attainment, health insurance coverage at Census tract level.

Based on the test results, nine factors are selected for further analysis (Table 1). Building age, number of stories, and number of rooms are important indicators for retrofit costs and difficulty. Assessed land value and median housing value are indicators for property value. Median gross rent and vacancy rate affect rental incomes of apartment buildings. Population density implies the scale of impact of an earthquake event or vulnerability level. Educational attainment (indicated by high school completion rate in this study) is related to individual cognitive and learning skills, which are crucial to successful disaster preparedness.

Table 1. Variables used in the two-level logistic regression model (n = 4139).

Variable	**Level**	***mean***	***sd***	***min***	***max***
Retrofit outcome		0.77	0.42	0	1
Building age (year)	1	92.03	23.66	36	145
Number of stories	1	2.78	0.60	1	7
Number of rooms	1	30.55	23.87	0	753
Assessed land value ($)	1	1,046,718	1,477,271	0	31,000,000
Median gross rent ($)	2	2,070	377	636	3,207
Median housing value ($)	2	1,357,857	333,272	570,600	2,000,001
Population density (people/mi^2)	2	19,430	7,952	1,332	62,418
Vacancy rate	2	0.089	0.041	0	0.225
Educational attainment	2	0.929	0.064	0.516	1
Use[CH]	1	0.018	0.133	0	1
Use[CM]	1	0.010	0.099	0	1
Use[MFR]	1	0.949	0.050	0	1
Use[SFR]	1	0.023	0.149	0	1
Tier[II]	1	0.107	0.292	0	1
Tier[III]	1	0.703	0.249	0	1
Tier[IV]	1	0.190	0.353	0	1

Note: *sd* = standard deviation; Use[CH] = commercial hotels; Use[CM] = commercial miscellaneous; Use[MFR] = multifamily residential; Use[SFR] = single-family residential; Tier[II] = retrofit tier II; Tier[III] = retrofit tier III; Tier[IV] = retrofit tier IV.

In addition, two factors related to regulatory impacts are analyzed: building use and retrofit tier. Building use reflects the difficulty of owners in financing retrofit projects and recouping retrofit costs. In San Francisco, the cost recovery program allows apartment to pass the full amount of retrofit costs to tenants over 20 years, while no financial incentive exists for retrofitting commercial buildings. It should be noted that building use may have wide implications that are not explored in this study. Table 1 uses dummy variables to describe retrofit tier and building use categories, with 0 and 1 denoting the absence and presence of a subcategory, respectively. Commercial retail and tier I are not analyzed because of very small sample sizes.

A two-level logistic regression model is developed to predict the retrofit probability of soft-story buildings conditional on the above factors. Level 1 of the model contains six factors at the building level (Table 1). Level 2 includes five factors at the Census tract level (Table 1). A random intercept is used to capture difference between Census tract groups, which contributes to 5% of the retrofit outcome. Level-1 predictor variables are cluster-mean centered and level-2 predictor variables are grand-mean centered. Thus, level-1 coefficients only reflect within-group differences and level-2 coefficients only reflect between-group differences.

This study uses Census 2015-2019 American Community Survey data at Census tract level from NHGIS [6]. The soft-story inventory with compliance status on September 25, 2020, is obtained from DataSF [3]. Assessor's data is derived from DataSF and the ATTOM^{TM} database [7]. All values are adjusted to 2019 US dollars.

Results

Regression analysis results indicate that retrofit probability is highly dependent on building age, building use, and retrofit tier ($p < .001$) and moderatley dependent on vacancy rate ($p < .01$). There are also strong correlations between retrofit probability and number of stories, land value, and median housing value ($p < .05$) and a moderate correlation between retrofit probability and educational attainment ($p < .1$).

Retrofit probability may increase with building height (number of stories), median housing value, median gross rent, educational attainment, and population density, and decrease with building age, size (number of rooms), land value, and vacancy rate (Fig.1). The likelihood that a seven-story building is retrofitted is, *ceteris paribus*, 0.2 higher than that of a one-story building. The mean likelihood may grow by 0.15 as median housing value rises from \$0.6 million to \$2.0 million or as high school compeltion rate (educational attainment) rises from 0.65 to 0.79. The mean likelihood may decrease by 0.15 as building age increases from 36 to 145 years or as vacancy rate increases from 0 to 23%. Moreover, buildings in earlier Tier II are more likely to be retrofitted than those in later Tiers III and IV. Single-family residential buildings (i.e., condos) are most likely to comply with retrofit ordinance requirements, followed by multifamily residential buildings (i.e., apartments), commercial miscellaneous, and commercial hotels.

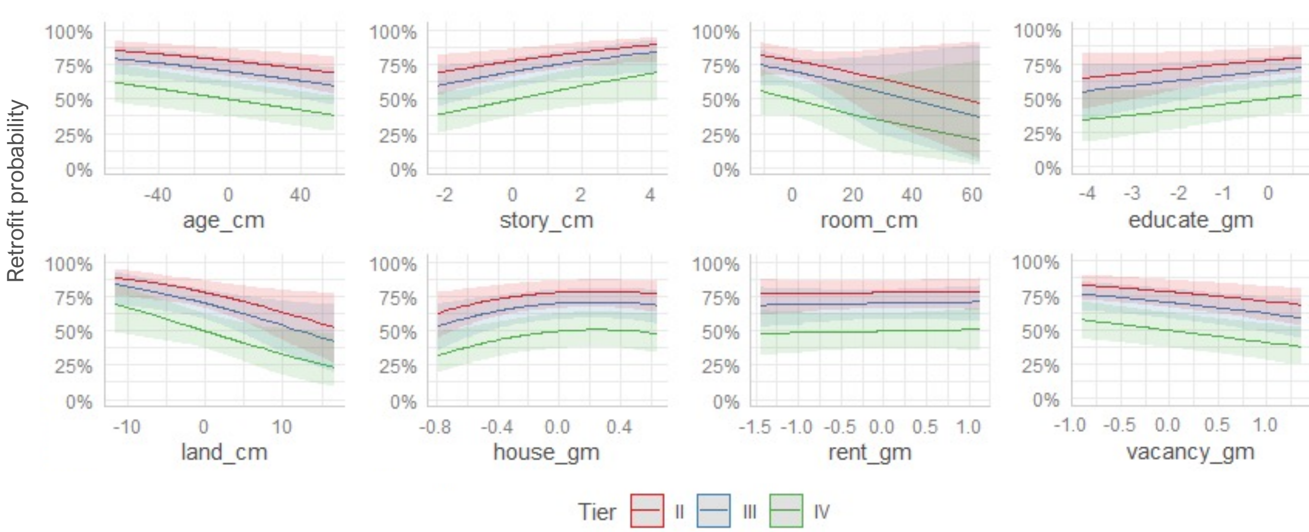

Figure 1. Retrofit probability as a function of predictor variables for three retrofit tiers. The shaded area represents the 95% confidence interval. The appended "cm" and "gm" denote cluster-mean centering and grand-

mean centering, respectively.

Discussion and Conclusion

The preliminary results indicate that regulatory factors may surpass individual, economic, and social factors in governing retrofit decisions. Prioritizing buildings for retrofit can motivate owners to strengthen buildings at higher risk (earlier tiers). In addition, there can be more impediments (e.g., cost recovery, business relocation, triggers for other compliance demands) to retrofit adoption for commercial buildings as retrofit probability of commercial buildings is much lower than that of residential buildings when other analyzed factors are equal.

Moreover, old, large buildings may discourage seismic upgrades because of high retrofit costs and difficulty (e.g., retrofit methods, displacement) [8]. High land value may decrease retrofit probability because of high costs for business interruption during renovation work and high motivation of owners in replacing the building if the improvement value of the building is much lower than its land value. In contrast, high median housing value may motivate owners to strengthen buildings because that can protect their investment and likely increase sale prices. High median gross rent and low vacancy rate may suggest high expected returns from retrofitted buildings and thus are favorable to retrofit implementation. High population density may also encourage mitigation actions in San Francisco because soft-story buildings are concentrated in high-density neighborhoods and tend to house a significant number of people in those neighborhoods, which makes seimic retrofits imperative. Education can improve risk perception and sense of responsibility of individuals and thus is favorable to retrofit adoption.

This article presents the methods and results for assessing the influence of individual, economic, social, and regulatory factors on San Francisco's soft-story program. Note that the influence may vary by region, future reserach may investigate the influence of those factors on retrofit programs of other cities [5].

References

1. City of San Francisco. *Ordinance No. 66-13*. March 25, 2013.
2. DataSF. *Map of Soft-Story Properties*. San Francisco's Department of Building Inspection, September 25, 2020.
3. Zhang Y, Fung J, Johnson K, and Sattar S. Review of Seismic Risk Mitigation Policies in Earthquake-Prone Countries: Lessons for Earthquake Resilience in the United States. *Journal of Earthquake Engineering* 2021; DOI:10.1080/13632469.2021.1911889.
4. NDC. *Funding URM Retrofits, Report to City of Seattle from National Development Council*, May 2019.
5. Zhang Y, Fung J, Johnson K, and Sattar S. Motivators and Impediments to Sesimic Retrofit Implementation: A Case Study in California. Submitted to *Earthquake Spectra*, September 2021.
6. Manson SM, Schroeder JP, Van Riper D, Kugler T, and Ruggles S. *IPUMS National Historical Geographic Information System (NHGIS): Version 15.0*. Minneapolis, MN, 2020.
7. ATTOM[TM]. *Property Data*. https://www.attomdata.com/data/property-data/, last accessed June 15, 2021.
8. Fung J, Sattar S, Butry D, and McCabe S. A Predictive Modeling Approach to Estimating Seismic Retrofit Costs. *Earthquake Spectra* 2020; **36**(2): 579-598.

Appendix

The following two-level logistic regression model is used to predict retrofit probability.

$$\ln\left[\frac{P(y_{ij}=1)}{1-P(y_{ij}=1)}\right] = \beta_0 + \beta_{age}x_{age,ij} + \beta_{story}x_{story,ij} + \beta_{room}x_{room,ij} + \beta_{land}x_{land,ij} + \beta_{rent}x_{rent,ij} + \beta_{house}x_{house,ij} + \beta_{house2}x_{house2,ij} + \beta_{pop}x_{pop,ij} + \beta_{vac}x_{vac,ij} + \beta_{edu}x_{edu,ij} + \beta_{use}x_{use,ij} + \beta_{tier}x_{tier,ij} + u_{0,j} \quad (1)$$

where y_{ij} is the outcome variable of cluster j subject i. $P(y_{ij}=1)$ is the probability that the building is retrofitted. x_{ij} is the predictor of cluster j subject i. β_0 and $u_{0,j}$ are fixed and random intercepts. $\beta_{age,} \dots \beta_{tier}$ are fixed slopes.