巨灾风险建模与风险管理

关键词: Seismic Loss、Life-Long Insurance、Retrofitting

苏锦华 2021.10.27

Available at https://github.com/SmartDataLab/DR-Share

Written by Marp and Mermaid in Markdown

Background

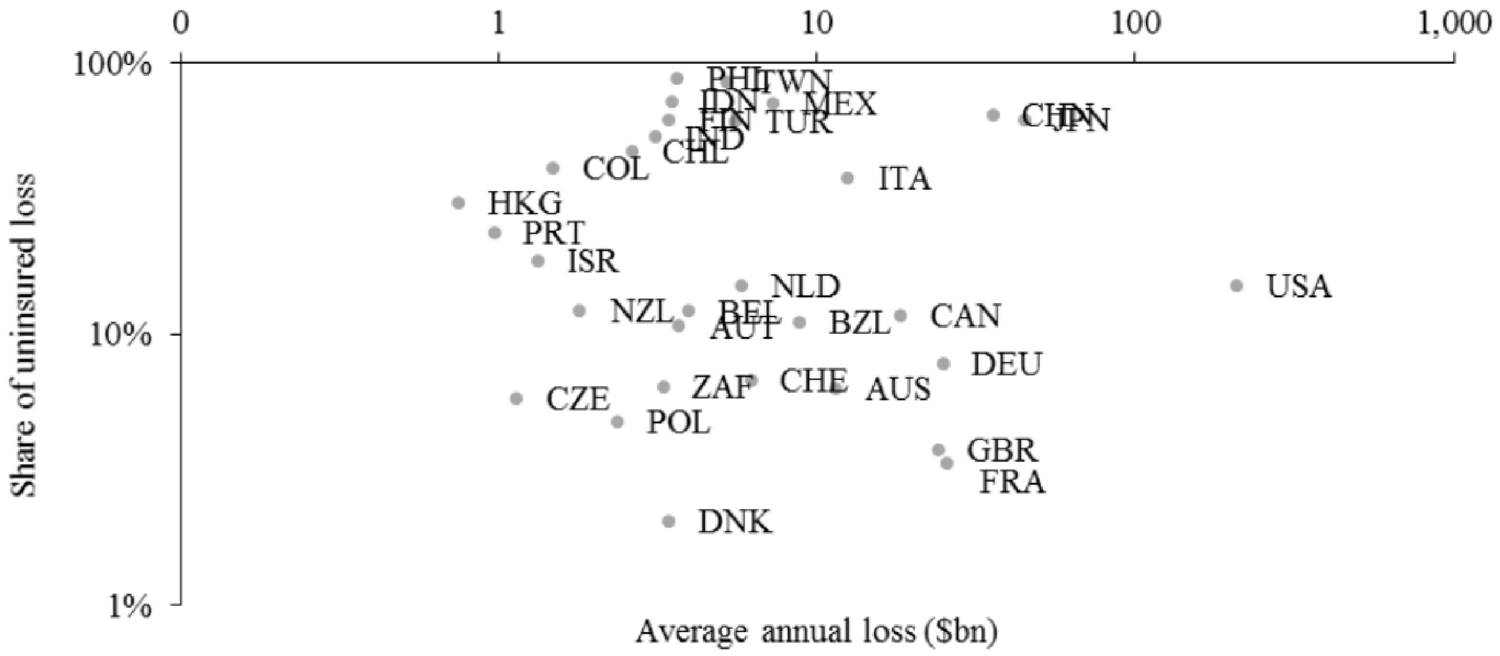


Figure 3.3.2: Country profile regarding the share of uninsured loss (modelled) and the annual average loss consecutive to natural catastrophes (modelled), released by Swiss RE (Holzheu and Turner 2018).

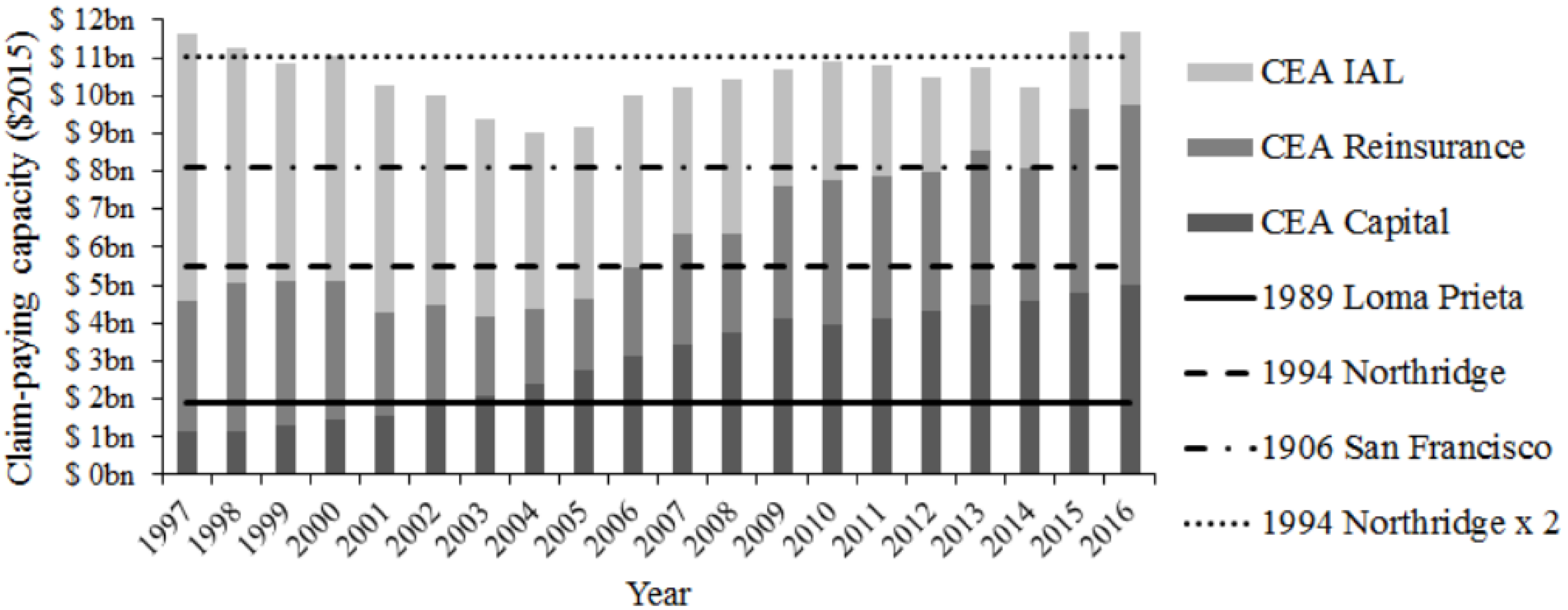


Figure 2.7: CEA's claim-paying capacity according to the source of funds: the CEA's capital, the CEA reinsurance cover, and the Industry Assessment Layer (IAL) corresponding to the funds provided by the CEA's insurance company members. The lines correspond to the loss incurred by the CEA if the 1906 San Francisco, the 1989 Loma Prieta or the 1994 Northridge earthquakes occur today. The '1994 Northridge x2' corresponds to a hypothetical earthquake causing a direct economic loss twice higher than the 1994 Northridge earthquake. Source: after CEA Financial Statements.

Previous Methods and Problem

- mutualisation(current)
- parametric(new) -- Stakeholders
- allocation
- sociétés mutuelles d’assurances -- CAT-NAT

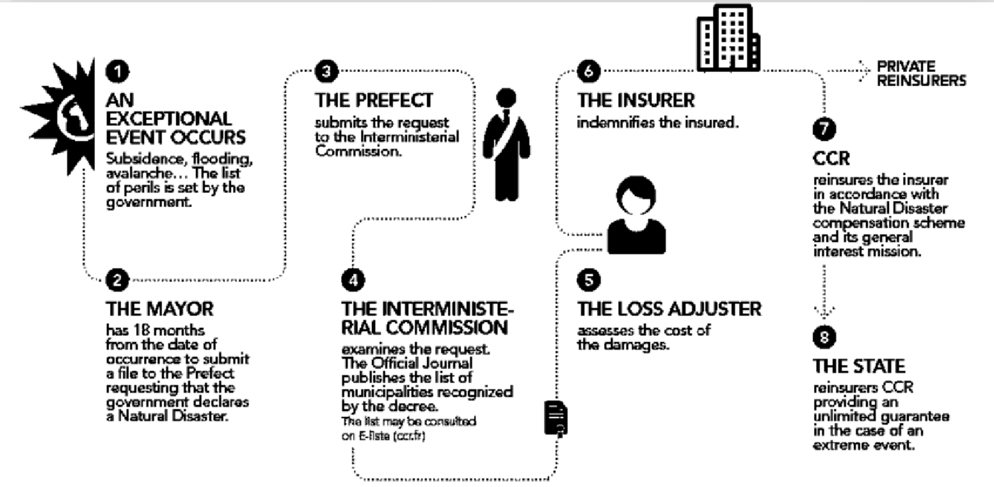
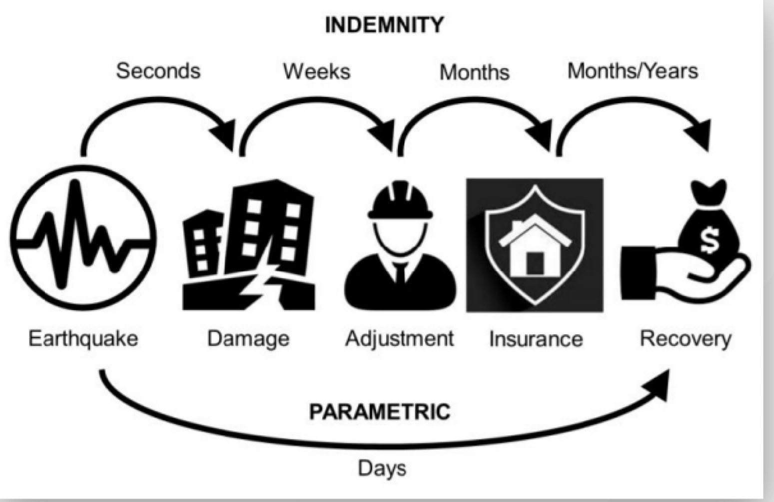


Figure 3.3.1: Scheme of the French CAT-NAT compensation scheme. Source : Caisse Centrale de Réassurance (2015).



Previous Research Target

This study focuses on the following variables about earthquake insurance policies:

- the total written premium (W_N), corresponding to the total amount paid by policyholders to insurance companies during the year N;
- the take-up rate (t_N), defined as the ratio between the number of policies with an earthquake coverage (Nb_N) and those with a fire coverage (Fi_N);
- the annual average premium (P_N), equal to W_N over Nb_N;
- the average premium rate (p_N) equal to the ratio between the annual average premium amount P_N and the average value of the good insured (here a house), later referred as the average sum insured (ASI_N).

Target cont.

- Utility of homeowners

$$g_N(t_N) = K - t_N \times P_N - K \times (1 - t_N) \times \mathrm{B}_{\mathrm{EQ}}(r_N)$$

$$t_N^{\text{Estimated}} = \underset{0 \leq t_N \leq 1}{\operatorname{argmax}} \mathbb{E}\left(U\left(g_N(t_N)\right)\right)$$

- CAT-NAT logit

$$\ln\left(\frac{\mathbb{P}(CN \mid (Pop, MSK))}{1 - \mathbb{P}(CN \mid (\text{ Pop }, MSK))}\right) = 0.75 \times \log_{10}(\text{ Pop }) + 2 \times MSK - 13.14$$

Challenge

- Homeowners' risk perception(individual -- country)
- Observation Data -- ShakeMap footprints
- Exposure: Asset Value Map & Damage Map

homeowners' risk perception

At the scale of a California homeowner, the average annual

probability to be affected by such an earthquake is only at 0.038%
The homeowners' risk perception is controlled by both the risk materiality (what kind of earthquakes are expected to occur?) and the risk tolerance (how much homeowners are ready to lose?).

homeowners' risk perception cont.

The lines AWRN = 70%, AWRN = 100% and AWRN =425% stand for the current situation, the
true risk level and the target value of AWRN for tN
Estimated=100%, at the current price at $980
(USD 2015), respectively. According to the first one (AWRN = 70%), half of homeowners
(tN
Estimated = 50%) are not willing to pay an average premium amount exceeding PN=$310 (USD
2015) per year, for an insurance cover. This would represent a 68% decrease in the price of

ShakeMap

For that, the ShakeMap footprints, released by the U.S. Geological Survey (USGS), are used. A ShakeMap footprint gives, for a historical earthquake, the modelled ground motions for several metrics, including the macroseismic intensity on the Modified Mercalli Intensity scale (MMI)

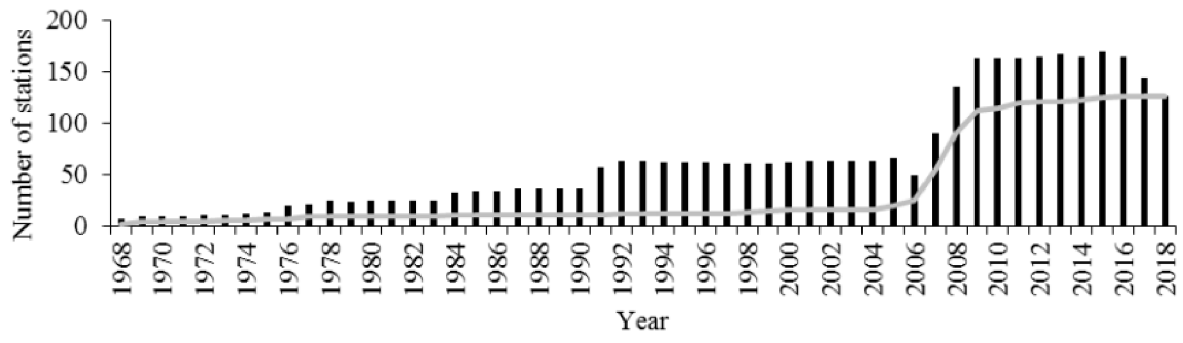


Figure 4.2.1: Number of operational seismic stations in Indonesia listed by the International Seismological Centre. The grey line corresponds to the number of stations still open in 2018.

ShakeMap Evluation

$$\mathbb{P}\left(S_N \geq k\right) = \mathbb{P}\left(\sum_{i \in N} \left[\mathrm{PGA}_i^{50} \geq \mathrm{PSHA}_i\right] \geq k\right) = \binom{\#N}{k} b^k (1-b)^{\#N-k}$$

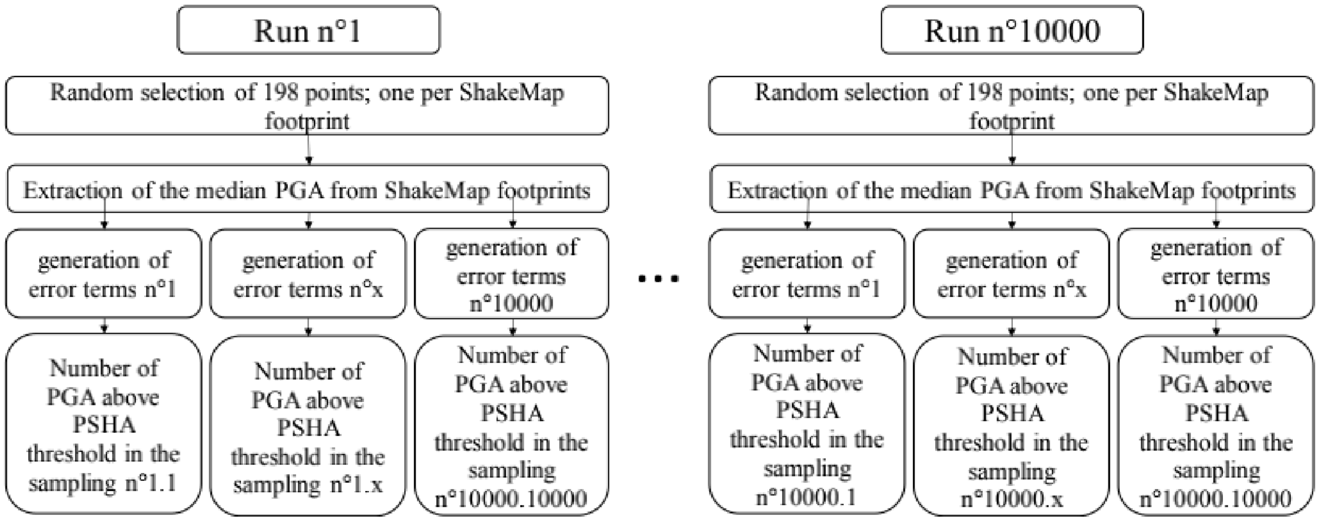


Figure 4.2.7: Procedure for sampling a stochastic set of points on which PSHA maps are tested in the case of 10,000 rock site samples and 10,000 PGA error samples for each rock site sample.

ShakeMap Result

PSHA maps: Probabilistic Seismic Hazard Assessment

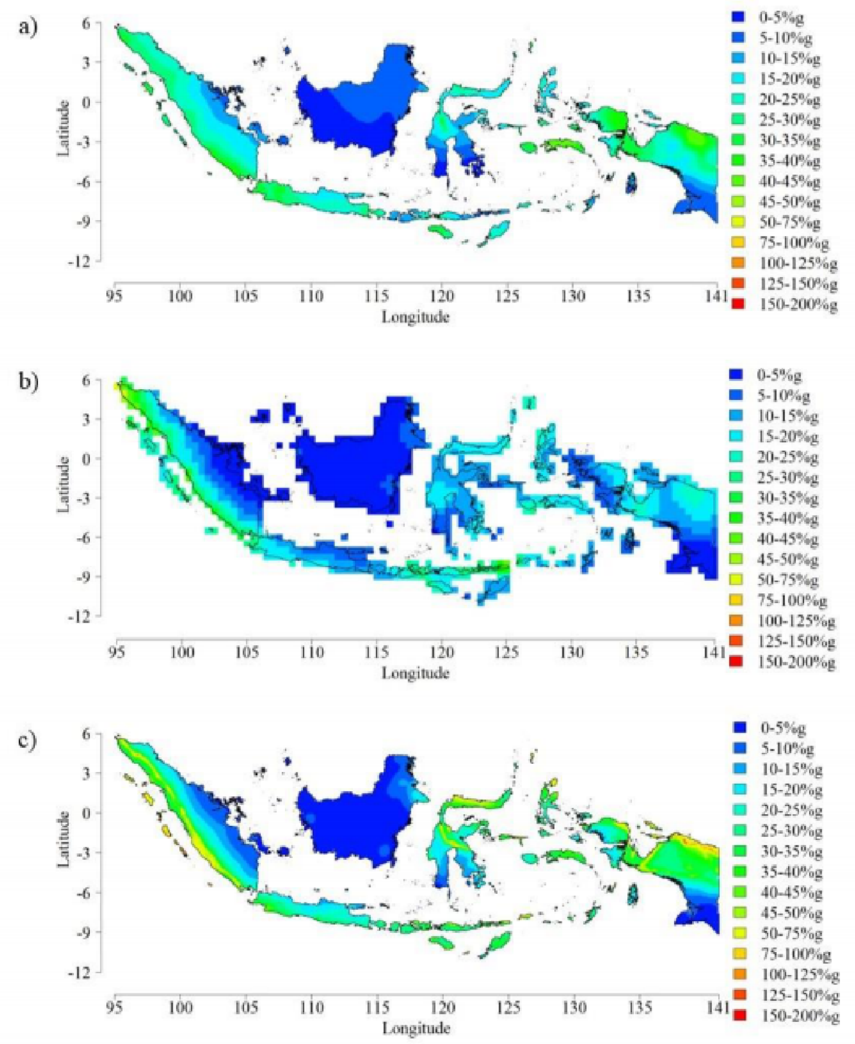


Figure 4.2.8: PSHA maps considering PGA for rock sites, a period T=50y and a probability of exceedance p=10%. a) GSHAP (Giardini et al. 1999); b) GAR2015 (CIMNE and INGENIAR 2015); c) SNI2017 (Irsyam et al. 2017).

Asset Value Map

- GDP based

$$\text{Normalized Damage}\ {}_t^s = \text{Damage}\ {}_t \times \frac{\text{GDP Deflator}\ {}_\text{s}}{\text{GDP Deflator}\ {}_t} \times \frac{\text{Pop}\ {}_\text{s}}{\text{Pop}\ {}_t} \times \frac{\text{Wealth per capita}\ {}_s}{\text{Wealth per capita}\ {}_t}$$

$$\text{GDP Deflator}\ {}_t = \frac{\text{Nominal}\ GDP_t}{\text{Real}\ GDP_t}$$

- Remote Sensing Based
  - Night Light
  - Phone Signal

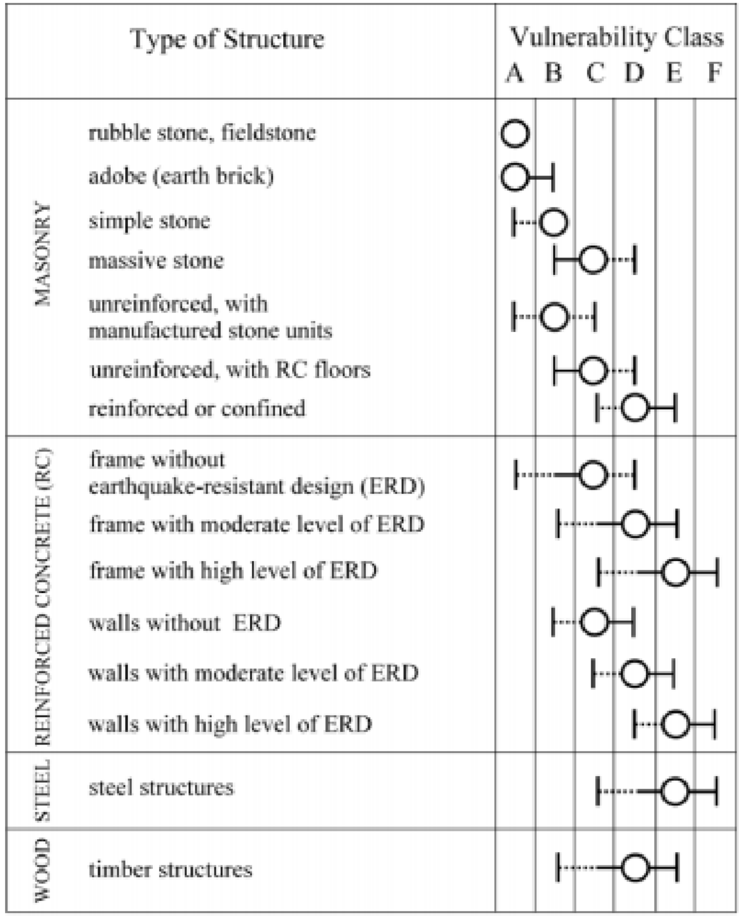
Material Damage Map

$$HD^B = 2.5 \times \left(1 + \tanh\left(\frac{1 + 6.25 \times V - 13.1}{2.3}\right)\right)$$

Table 4.3.7. Extract of the Global Building Inventory implemented in the PAGER program for the residential buildings in China (CHN), India (IND) and Nepal (NPL). The "Str. Code" column gives the structure type from the WHE database associated to each structure description given by the PAGER. Source: after WHE (Brzev et al. 2004);Jaiswal and Wald (2008).

Land Use	Str. Code	Description	CHN	IND	NPL
Rural	W	Wood	10%	13%	0%
	W	Wood stud-wall frame with plywood/gypsum board sheathing.	0%	0%	20%
	RC	Nonductile reinforced concrete frame with masonry infill walls	3%	1%	0%
	A	Adobe blocks (unbaked sundried mud block) walls	40%	0%	43%
	A	Adobe block, mud mortar, wood roof and floors	0%	37%	0%
	St	Rubble stone (field stone) masonry	3%	12%	0%
	St	Rectangular cut stone masonry block with cement mortar	0%	0%	11%
	UM	Unreinforced fired brick masonry	10%	35%	0%
	UM	Unreinforced brick masonry in mud mortar without timber posts	35%	0%	26%
	NA	Not specified (unknown/default)	0%	2%	0%
Urban	W	Wood	5%	4%	0%
	W	Wood stud-wall frame with plywood/gypsum board sheathing.	0%	0%	9%
	RC	Ductile reinforced concrete moment frame with or without infill	12%	0%	0%
	RC	Reinforced concrete shear walls	5%	0%	0%
	RC	Nonductile reinforced concrete frame with masonry infill walls	5%	6%	2%
	A	Adobe blocks (unbaked sundried mud block) walls	4%	0%	20%
	A	Adobe block, mud mortar, wood roof and floors	0%	11%	0%
	St	Rubble stone (field stone) masonry	2%	7%	0%
	St	Rectangular cut stone masonry block with cement mortar	0%	0%	55%
	UM	Unreinforced fired brick masonry	61%	69%	0%
	UM	Unreinforced brick masonry in mud mortar without timber posts	5%	0%	14%
	UM	Concrete block unreinforced masonry with lime or cement mortar	2%	0%	0%
	NA	Not specified (unknown/default)	0%	3%	0%

Table 4.3.5: Vulnerability classes by structure type as defined in the EMS-98 macroseismic scale. Source Grünthal 1998.



most likely vulnerability class; — probable range;
·····range of less probable, exceptional cases

Model Preview

For several seismic-prone countries, current earthquake insurance solutions cover only a small part of the economic loss. Innovative insurance products like parametric insurance are emerging for which the compensation is calculated upon a trigger instead of a claim amount, covering more people but with drawbacks due to probable difference between the insurance compensation and the actual loss.

Property & Advantage

- **Practicability**:
  `the compensation is to rebuild the insured house, instead of paying a financial amount;`
- **Allocation**:
  `the model leverages both on long-term financial investment and seismic retrofitting of the insured buildings to make the premium amount affordable;`
- **Retrofitting**:
  `joint participation of the public authorities and the homebuilder companies in this insurance model are expected since the first ones are the key player in risk prevention plans and the second ones are the beneficiary of this new market .`

Notation

The first section introduces some key insurance notions, later used in this study to describe this proposed earthquake insurance model.

$$P_1^M + P_2^M = \frac{\mathbb{E}\left(L_{EQ}\right) - F}{\mathbb{E}\left(Y_{EQ}\right)}$$

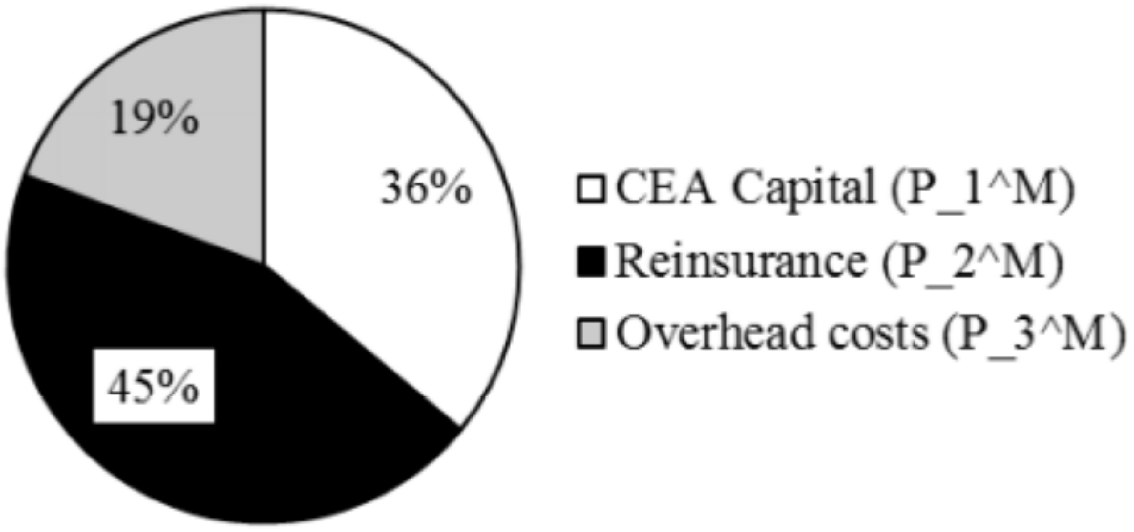


Figure 5.2: Allocation of California Earthquake Authority (CE
2017. Source: after California Earthquake Authority (2018e).

The premium shares corresponding to the reinsurance ($P2M$) and the CEA overhead costs ($P3M$) are spent each year and therefore, cannot be invested on financial markets. Therefore, only the share of the premium not used to pay claims and retained as capital (Fig. 5.2: $P1M$ = 36%PM) is available for investing on financial markets. However, since the funds are dedicated to pay future insurance claims, they must be very immediately available and only invested in very secure and liquid financial products. For a given currency, one of the most secure financial products to invest in is the long-term treasury bonds of high-rated countries.

A life insurance mechanism to increase affordability

Next, the choice to build it according to life insurance principles instead of property insurance scheme is motivated.

- Calculate the annual premium amount P under the allocation.

$$P_1^{EQ} = P_1 \times (1+t_I)^{Y_{EQ}-1} + P_1 \times (1+t_1)^{Y_{EQ}-2} + \cdots + P_1 \times (1+t_1) + P_1$$

$$\mathbb{E}\left(P_1^{EQ}\right) = P_1^M \times \mathbb{E}\left(Y_{EQ}\right) = \left(\mathbb{E}\left(L_{EQ}\right) - F\right) \times \frac{36\%}{81\%}$$

$$\sum_{i=1}^{+\infty} \left[P_2 \times \mathbb{P}\left(Y_{EQ} \geq i\right)\right] = \frac{45\%}{81\%} \times \left(\mathbb{E}\left(L_{EQ}\right) - F\right)$$

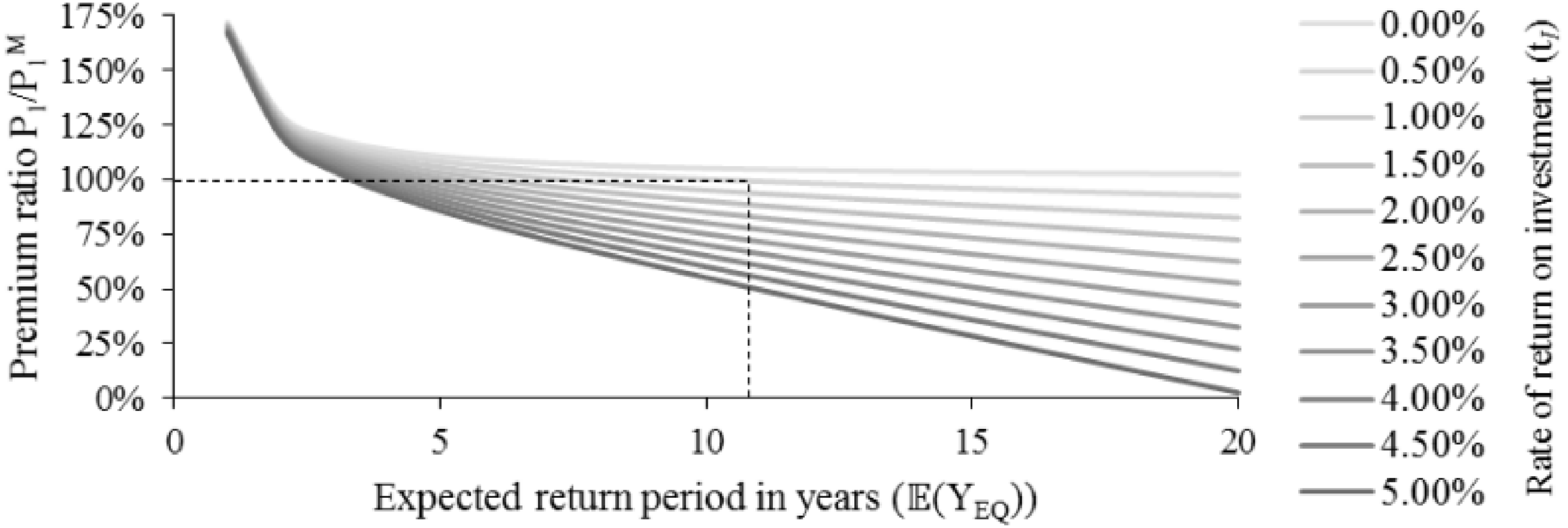


Figure 5.5: Ratio between the annual premium amount calculated under the allocation insurance scheme (P_1) and the mutualisation insurance scheme (P_1^M), according to the expected return period $\left(\mathbb{E}\left(Y_{EQ}\right)\right)$ of the next earthquake causing a claim. Each curve corresponds to a different rate of return on investment (t_I) on the financial markets.

Case study

In the third part, a probabilistic loss model combining the UCERF3 (Field et al. 2013) and the HAZUS-MH MR5 (Federal Emergency Management Agency 2010) models for California is introduced to then produce premium amount estimates.

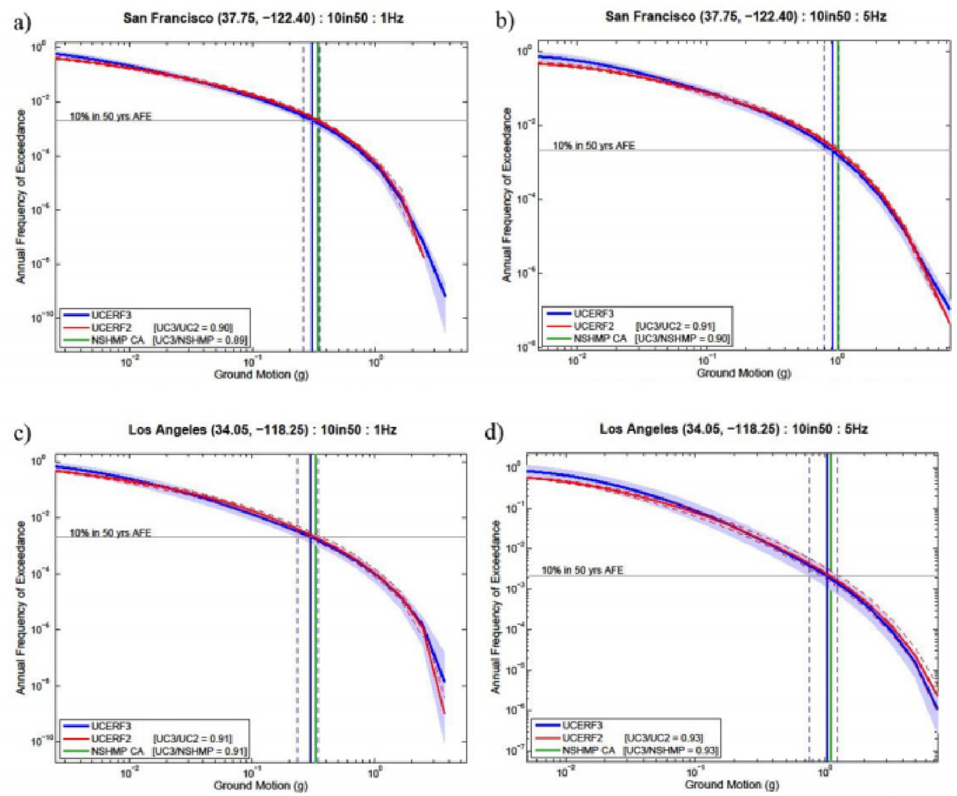


Figure 5.6: Maximum considered earthquake (MCE$_R$) ground motion response acceleration at 0.2 and 1 seconds for San Francisco and Los Angeles estimated from different models. Source: USGS (https://pubs.usgs.gov/of/2013/1165/data/UCERF3_SupplementalFiles/UCERF3.3/Hazard/HazardCurves/Sites/index.html).

Figure 5.7: Screen shots of the Global Slope-Based proxy for the Vs30 soil profile for San Francisco and Los Angeles areas. Source: USGS (https://earthquake.usgs.gov/data/vs30/).

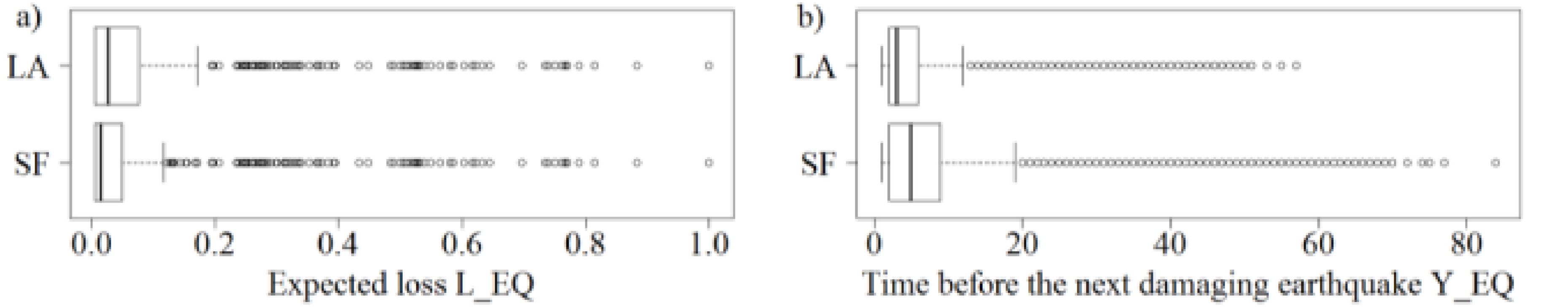


Figure 5.8: Distribution of: a) the expected loss (L_{EQ}) and b) the time before the next damaging earthquake (Y_{EQ}), as calculated with the UCERF3/HAZUS-MH MR5 model for a Pre-Code seismic design level wooden house located in Los Angeles (LA: 118.25°W; 34.05°N) and San Francisco (SF: 122.40°W; 37.75°N). The deductibles amount is taken equal to 0. The box represents the first and the third quartiles and the thick solid line the second quartile. The length of the right-hand side dotted line is equal to 1.5 times the box length. On the left-hand side, the dotted line is capped by the minimum value of the distribution (equal to 0 for L_{EQ} and 1 for Y_{EQ}). Dots show values beyond the end of dotted lines (materialized by the small solid vertical line). Source: after UCERF3.3 Hazard Analysis Sites.

Leveraging on building retrofitting works

The fourth section is about the benefit of earthquake retrofitting works for the insurance scheme.

Table 5.1: Time in years between the insurance policy issuance and the beginning of the retrofitting works required to reach a given seismic design level, according to the initial seismic design code (*IC*). The time is equal to 0 when the building is already at the seismic design level or above at the time of the insurance policy issuance.

Initial seismic design code (*IC*)	Time in years before the retrofitting works to reach the level: Low Code (*LC*)	Moderate Code (*MC*)	High Code (*HC*)
Pre Code (*PC*)	T^{LC}	T^{MC}	T^{HC}
Low Code (*LC*)	0	T^{MC}	T^{HC}
Moderate Code (*MC*)	0	0	T^{HC}
High Code (*HC*)	0	0	0

$$\sum_{i=1}^{+\infty} \left[P_1 \times (1+t_l)^{i-1} \times \mathbb{P}\left(Y_{EQ} \geq i\right)\right]$$

$$\begin{aligned}
&= \sum_{i=1}^{T^{LC}} \left[P_1 \times (1+t_I)^{i-1} \times \mathbb{P}\left(Y_{EQ} \geq i \mid Y_{EQ} \leq T^{LC}\right)\right] \times \mathbb{P}\left(Y_{EQ} \leq T^{LC}\right) \\
&+ \sum_{i=1}^{T^{MC}} \left[P_1 \times (1+t_I)^{i-1} \times \mathbb{P}\left(Y_{EQ} \geq i \mid T^{LC} < Y_{EQ} \leq T^{MC}\right)\right] \times \mathbb{P}\left(T^{LC} < Y_{EQ} \leq T^{MC}\right) \\
&+ \sum_{i=1}^{T^{HC}} \left[P_1 \times (1+t_1)^{i-1} \times \mathbb{P}\left(Y_{EQ} \geq i \mid T^{MC} < Y_{EQ} \leq T^{HC}\right)\right] \times \mathbb{P}\left(T^{MC} < Y_{EQ} \leq T^{HC}\right) \\
&+ \sum_{i=1}^{+\infty} \left[P_1 \times (1+t_1)^{i-1} \times \mathbb{P}\left(Y_{EQ} \geq i \mid T^{HC} < Y_{EQ}\right)\right] \times \mathbb{P}\left(T^{HC} < Y_{EQ}\right)
\end{aligned}$$

$$\begin{aligned}
\mathbb{E}\left(L_{EQ}\right) = \mathbb{E}\left(L_{EQ} \mid Y_{EQ} \leq T^{LC}\right) \times \mathbb{P}\left(Y_{EQ} \leq T^{LC}\right) \\
+ \mathbb{E}\left(L_{EQ} \mid T^{LC} < Y_{EQ} \leq T^{MC}\right) \times \mathbb{P}\left(T^{LC} < Y_{EQ} \leq T^{MC}\right) \\
+ \mathbb{E}\left(L_{EQ} \mid T^{MC} < Y_{EQ} \leq T^{HC}\right) \times \mathbb{P}\left(T^{MC} < Y_{EQ} \leq T^{HC}\right) \\
+ \mathbb{E}\left(L_{EQ} \mid T^{HC} < Y_{EQ}\right) \times \mathbb{P}\left(T^{HC} < Y_{EQ}\right)
\end{aligned}$$

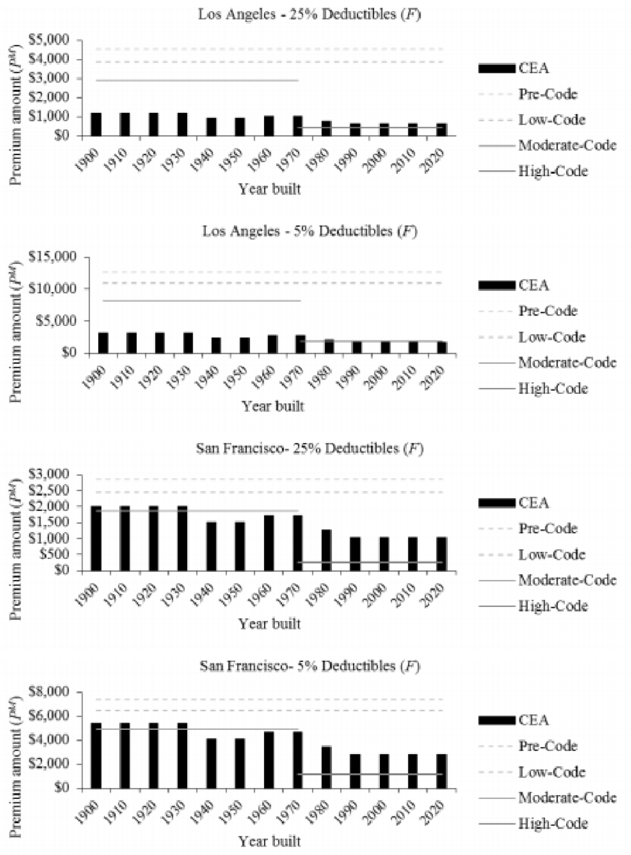


Figure 5.9: Comparison of the annual premium amount modelled under the mutualisation scheme for different seismic design levels (grey continuous and dashed horizontal lines) and offered by the CEA (black bars). Results are presented for a wooden house located in San Francisco (postal code used: 94102) and Los Angeles (postal code used: 90001),

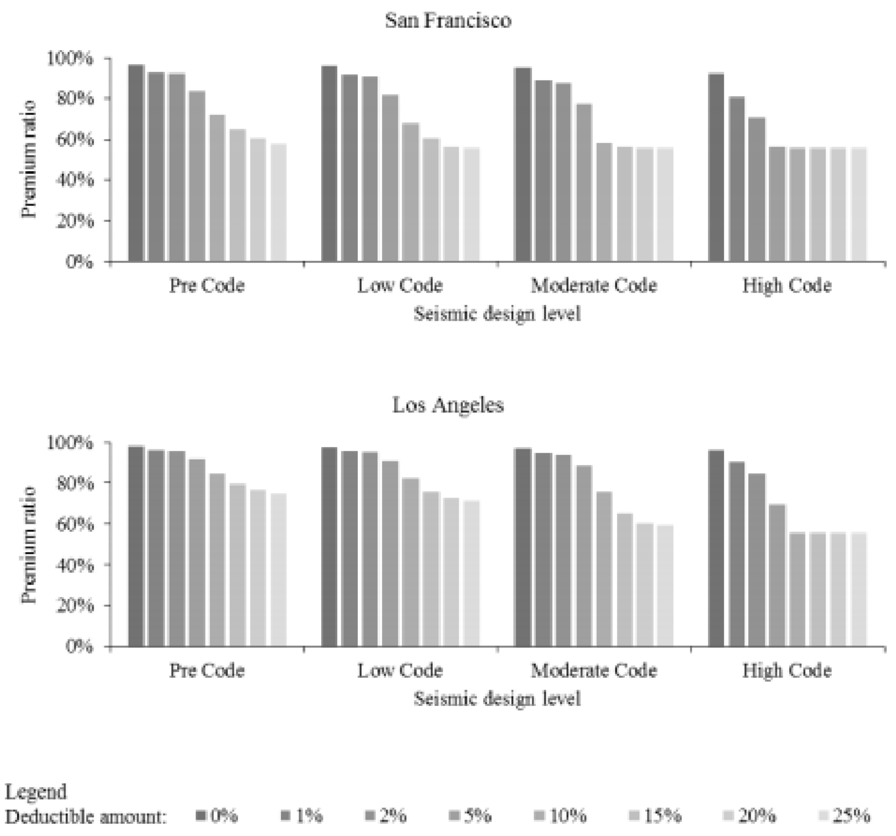


Figure 5.10: Premium ratio between the allocation and the mutualisation insurance scheme (P/P^M) for different seismic design levels and deductible amounts in San Francisco and Los Angeles. A premium ratio below 100% means that the premium is lower in the allocation than in the mutualisation insurance scheme.

Involving homebuilder companies and public authorities

Finally, the contribution of homebuilder companies and public authorities to this insurance scheme is investigated.

$$\text{expected earnings} = \begin{cases} b \times W_{LC} & \text{for retrofitting works from } PC \text{ to } LC \\ b \times W_{MC} & \text{for retrofitting works from } LC \text{ to } MC \\ b \times W_{HC} & \\ b \times \mathbb{E}\left(L_{EQ}\right) & \text{for retrofitting works from } MC \text{ to } HC \\ \text{ for repairs/reconstruction works} & \end{cases}$$

$$m = \begin{cases} \mathbb{E}\left(\min\left(T^{LC}; Y_{EQ}\right)\right) & \text{if } IC = PC \\ \mathbb{E}\left(\min\left(T^{MC}; Y_{EQ}\right)\right) & \text{if } IC = LC \\ \mathbb{E}\left(\min\left(T^{HC}; Y_{EQ}\right)\right) & \text{if } IC = MC \\ E\left(Y_{EQ}\right) & \text{if } IC = HC \end{cases}$$

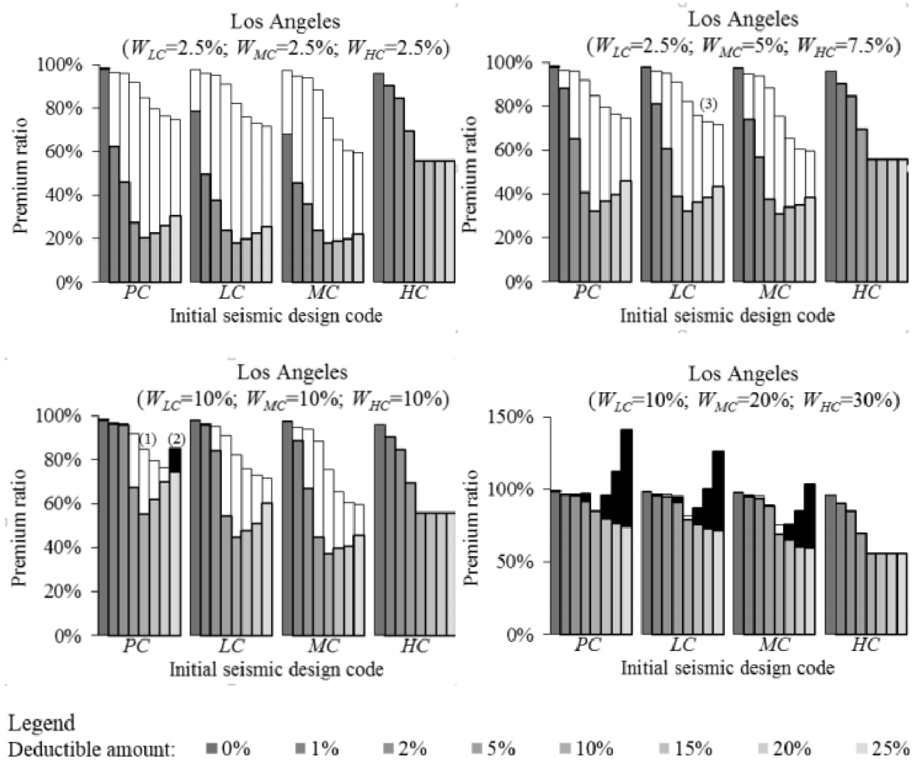


Figure 5.11: Premium ratio for the insurance cover including retrofitting works for various retrofitting costs (W_{LC}, W_{MC} and W_{HC}). The insured building considered is located in Los Angeles and with different initial seismic design codes (*IC*): Pre-Code (*PC*), Low-Code (*LC*), Moderate-Code (*MC*) and High-Code (*HC*). Grey bars show the premium ratio value for different levels of deductible amount (*F*). White and black bars on the top of the grey bars show when the premium ratio including retrofitting works is lower and higher than the previous premium ratio obtained without retrofitting works (Fig. 5.10), respectively. Tags (1), (2) and (3) refer to examples described in the text.

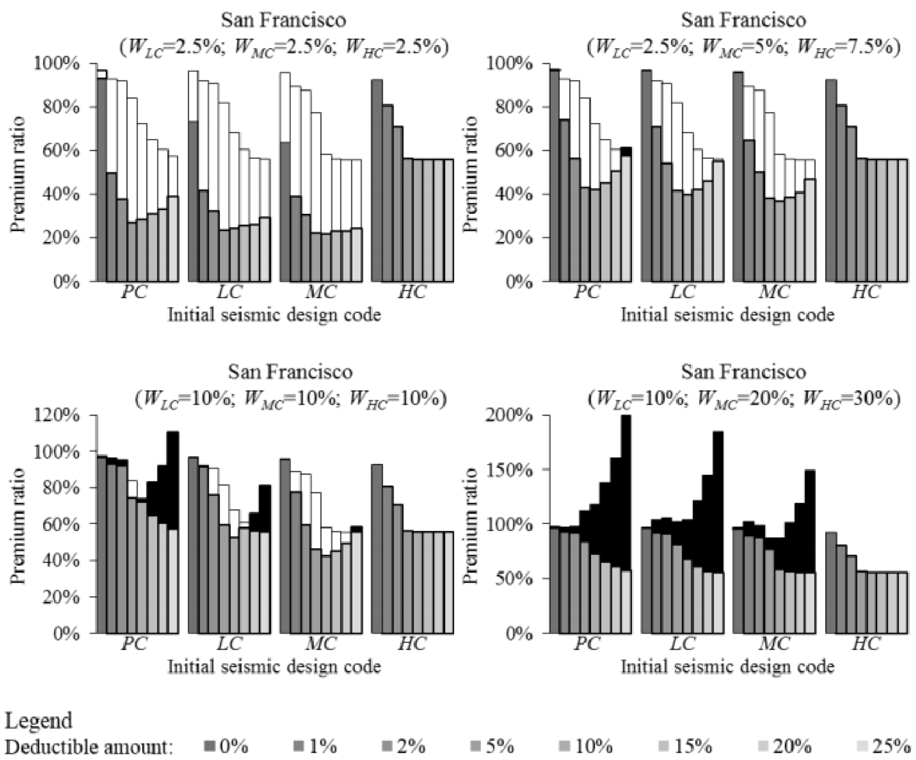


Figure 5.12: Premium ratio for the insurance cover including retrofitting works for various retrofitting costs (W_{LC}, W_{MC} and W_{HC}). The insured building considered is located in San Francisco and with different initial seismic design codes (*IC*): Pre-Code (*PC*), Low-Code (*LC*), Moderate-Code (*MC*) and High-Code (*HC*). Grey bars show the premium ratio value for different levels of deductible amount (*F*). White and black bars on the top of the grey bars show when the premium ratio including retrofitting works is lower and higher than the previous premium ratio obtained without retrofitting works (Fig. 5.10), respectively.

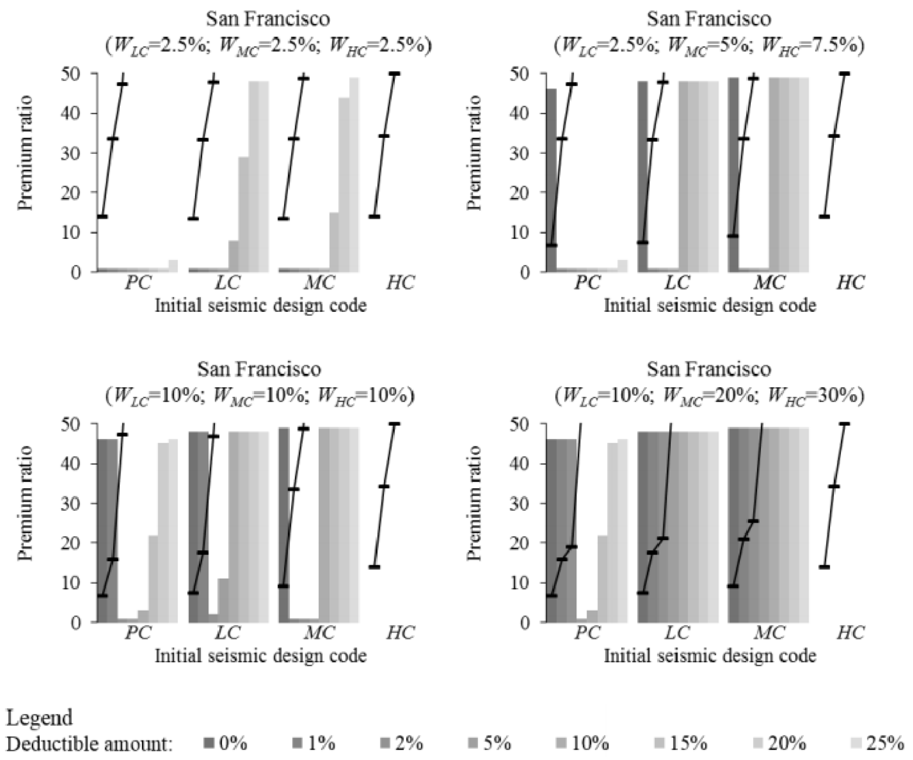


Figure 5.14: Illustration of the maturity (m) of repairs/reconstruction or retrofitting works for a building located in San Francisco and for different retrofitting costs (W_{LC}, W_{MC}, W_{HC}), deductible amount (F) and initial seismic design code (IC): Pre-Code (PC), Low-Code (LC), Moderate-Code (MC) and High-Code (HC). The black line represents $\mathbb{E}(Y_{EQ})$, the expected time before the first earthquake causing a damage above the deductible amount F. The histogram shows the time for the next retrofitting works (e.g. from LC to MC when the initial seismic design code is LC). On each graph, the maturity m corresponds to the minimum between the histogram and the black line.

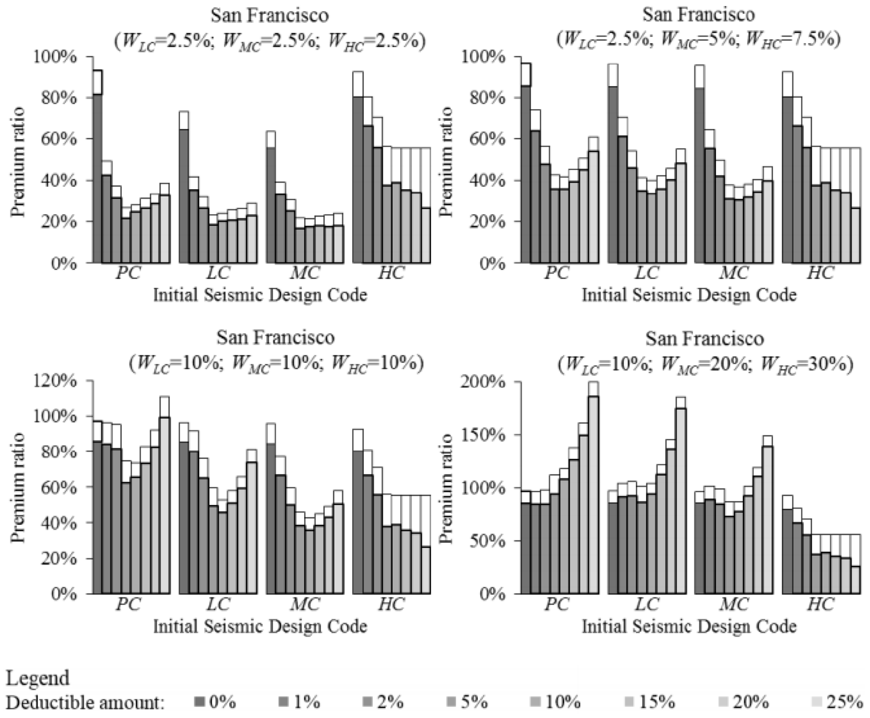


Figure 5.16: Premium ratios including the homebuilder companies' contributions (C_1, C_{LC}, C_{MC} and C_{HC}) for having the repairs/reconstruction and the retrofitting works. Grey bars show the premium ratio value for different level of deductible amount (F) considering the maximum homebuilder companies' contributions, calculated with an average income rate b=15% and a rate of return on investment t_H= 0.05%. The white bars at the top of grey bars represent the decrease of premium ratio thanks to the homebuilder companies' contributions (grey and white bars correspond to the premium ratios obtained with retrofitting works, illustrated in Fig. 5.14). The results are presented for San Francisco, several retrofitting costs (W_{LC}, W_{MC} and W_{HC}) and different initial seismic design code: Pre-Code (IC=PC), Low-Code (IC=LC), Moderate-Code (IC=MC) and High-Code (IC=HC). Tags (1), (2) and (3) refer to examples described in the text.

Conclusion

The model is tested with several case studies in California, where only 15\% of homeowners are currently covered against the earthquake risk. Results show that in most cases the price (i.e. premium amount and retrofitting costs) for this earthquake insurance model is lower than the premium amount considering the traditional earthquake insurance. For the optimal deductible amount, the decrease can even be three times lower than for classical model, by assuming a contribution from both the public authorities and the homebuilder companies. Such a decrease could raise the rate of California homeowners insured against earthquake risk from 15% up to 50%