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EARTHQUAKE RISK ESTIMATES FOR RESIDENTIAL CONSTRUCTION IN THE WESTERN UNITED STATES

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SUMMARY

This study presents relative seismic risk estimates for thirteen states: eleven coterminous west of the Rockies, Alaska and Hawaii. We focus on residential construction, considering both economic and insured exposure.

The loss estimation system uses a seismic source model based on the USGS 2002 National Seismic Hazard Mapping project. Building damage is estimated via spectral response-based vulnerability functions. This model incorporates variations in site conditions, construction design levels, building inventory, and insured value.

The thirteen western states are ranked in terms of their relative earthquake risk, with risk per state compared on the basis of both economic and insured loss cost. The consideration of insurance has a distinct effect on relativities due to differences in penetration rates and prevailing policy structures. This is particularly true for California; currently, the high deductibles and prices charged have driven down the purchase of earthquake policies to an extent that the insured proportion of potential earthquake losses is significantly less than it was at the time of the Northridge earthquake.

INTRODUCTION

Catastrophe modeling brings together a range of technical disciplines to estimate future losses from natural disasters, rather than relying only on a potentially incomplete historic record. For the earthquake peril these include seismology, civil and geotechnical engineering, economics, and actuarial science. Loss

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estimation tools influence public policy, mitigation decisions, local planning, insurance and reinsurance purchasing and pricing.

In this study, we present relative risk estimates for the thirteen states west of the Rocky Mountains. This analysis is noteworthy for incorporation of source modeling from the USGS 2002 National Seismic Hazard Maps [1], a new spectral response-based approach to building vulnerability [2, 3], and NEHRP-classified site condition data for all thirteen states. Risk estimates are presented in terms of average annual loss cost for economic and insured exposure. We focus on residential construction in this study, i.e. homeowners and renters only.

MODEL DESCRIPTION

Results provided in this analysis were generated from RiskLink, a proprietary insurance loss-estimation tool. It applies an event-based approach in which a set of stochastic events with corresponding rates has been defined, portfolio loss and variability are generated for each event, and exceedance probabilities of portfolio losses are calculated for various economic or insurance perspectives. The inputs to the RiskLink model are based primarily on publicly-available data and are summarized below.

Exposure and analysis resolution

Three exposure data sets were analyzed for this study. The first two comprise residential value for the western U.S. by ZIP Code, one total economic value and one insured value. The insured portfolio incorporates the local penetration rate of earthquake insurance purchase, policy conditions on deductibles and limits, and coverages for structures, contents, and additional living expenses. These were estimated from a value of public and private data sources, including insurance companies, state insurance regulators, the California Earthquake Authority, the U.S. Census, gross domestic product, Dun & Bradstreet square footage, Means construction costs, and other statistical factors.

The third was used to make a relative risk map and comprised a portfolio spaced on a variable grid for the thirteen western states considered. Grid cells were of approximately 1-, 5-, or 10-km size, with finer resolution used in areas of high exposure and/or hazard. Each cell contained a uniform value, split 65% structure / 35% contents, with the default inventory of residential building stock for the state.

Seismic source model

The fundamental inputs for the seismic source model are the documentation and parameters developed for the 2002 USGS National Seismic Hazard Maps. These are described for the lower 48 states, Hawaii, and Alaska by Frankel [1], Klein [4], and Wesson [5] respectively. For the purpose of this study, the most significant source modeling differences are the inclusion of "cascade" scenarios and/or time dependent recurrence on selected faults.

Cascade events refer to the potential for an earthquake to "jump" between fault segments during the rupture process. Recent examples include the 1992 Landers and 1999 Hector Mine events in the Mojave Desert, each of which ruptured smaller faults that had previously been considered separate sources. Incorporation of these events in the stochastic set generates earthquakes that are larger than would be possible on any of the constituent faults. There is a balancing effect on the model, however, as allowing the occurrence of cascades reduces the seismic moment available for smaller events and overall rates for the fault system will decrease. The model used in this study includes the cascade scenarios detailed in the 2002 USGS maps, including those defined for the Bay Area (WGCEP [6, 7]), as well as events on seven additional fault systems in California. Rate calculations for these follow the moment-balancing approach of Field [8] with values weighting three different probabilities of multi-segment rupture for each system.

The USGS hazard maps assume a Poisson (time-independent) process for estimating event probability within a given time window. A different approach to representing probability of event occurrence is the time-dependent model. Time-dependence explicitly recognizes the time interval since the last occurrence of an event associated with a given source and incorporates that information in estimating the probability of a future event on that same source. As the time since the last event increases, the probability of the event occurring in the near future will generally increase depending on the distribution used (cf Matthews [9]). Time-dependence is used for major fault systems in the state, including the San Andreas, Hayward-Rodgers Creek, San Jacinto, and Whittier-Elsinore fault. Key references include WGCEP [6, 7].

Ground motion attenuations vary by source type. Abrahamson [10], Boore [11], Campbell [12], and Sadigh [13] are considered for thrust and strike-slip crustal faults, with Spudich [14] included for extensional events. Subduction interface events combine Youngs [15], Sadigh [13], and Atkinson [16], while intraslab ground motions are modeled with the appropriate formulations of Youngs [15] and Atkinson [16]. Ground motion is calculated in terms of spectral acceleration from periods 0 to 4 seconds; the value experienced for a given location is a function of the building's predominant period.

Geotechnical site conditions

Digital geologic maps were assigned NEHRP site classes on the basis of published or inferred 30-m shear wave velocity. The approach follows the scheme and data of Wills [17]. Over 200 map coverages were incorporated into the site conditions dataset for the thirteen states in the study area. Resolution varies with data availability and exposure density. Small-scale geologic maps at 1:500,000 or 1:750,000 resolution were used for regional coverage. California was an exception, with 1:250,000 scale data used as the lowest resolution input. For primary urban areas, the input maps used were typically 1:100,000 scale or better.

For the purpose of analysis these data were aggregated to the ZIP Code and grid resolutions described above. Grid resolutions for the soil data are limited by the scale of the input map, so as not to exceed the applicability intended by the map authors. In both cases, aggregate values have been exposure-weighted with land use / land cover attribute data.

Liquefaction and landslide susceptibilities are also incorporated into the site inputs. Liquefaction susceptibilities were either aggregated from published maps (e.g. Knudsen [18]) or estimated from geology using the schema of Youd [19]. Landslide susceptibilities were developed following results of seismic hazard zoning studies by the California Geological Survey (e.g. [20]). These studies used a Newmark approach to define a matrix relating material properties and slope to susceptibility; these matrices were used directly where available and generalized for geologic materials elsewhere in California, Oregon, Washington, and Utah.

Vulnerability

The vulnerability module generates an estimate of the damage to exposure at a specific location as a function of the ground shaking for an event. The damage is expressed in terms of a mean damage ratio and a coefficient of variation around the mean. The RiskLink model uses separate vulnerability functions for building, contents, and time element losses.

Development of the damage functions followed the framework recently developed at the Pacific Earthquake Engineering Research Center (PEER), first described by Cornell [2]. The PEER approach considers both the entire spectrum of earthquake ground motion characteristics at a site and a building's response to that motion, and is thus referred to as spectral response-based vulnerability. See also Rahnama [3] for additional discussion of this implementation.

Contents modeling considers both damage from the intensity of ground shaking and from distress to the building itself. The former is more important at low shaking levels and is relatively independent of structure type, whereas at higher shaking the structural damage will contribute to the contents loss.

Users without data on the construction class for locations in their portfolio rely on inventory curves that store relative proportions of building types for different lines of business. For this study, the inventory data vary by state.

RESULTS

Model results are presented in terms of annualized loss cost, which is the modeled average annual loss normalized by the structure replacement value. Loss costs are given in units of $/$1,000 (per mille), a metric commonly used to quote insurance coverage premium, or have been normalized to the value for all of California.

Average annual loss (AAL) is the expected value of an exceedance probability loss distribution. It can be thought of as the product of the loss for a given event with its probability, summed over all events in the stochastic set. Normalizing the AAL by exposure facilitates comparison of relative risk, as it reduces potential differences in how the total building stock value is modeled in other studies. Population estimates from the US Census Bureau [21] are used as a proxy here for ordering of states by residential value.

Regional Loss Metrics

Figure 1 shows normalized residential loss costs for the thirteen western States considered in this study. This is similar to a seismic hazard map, but incorporates differences in construction inventory and damageability. It spans four orders of magnitude, providing a synoptic view of the relative seismic risk and context for the state and county level loss costs.

The highest point values are along the creeping section of the San Andreas fault system in central California. Average annual loss is strongly affected by event rates and the high relative rates of moderate earthquakes along this segment of the fault drive up the loss costs. Other notable areas include the southeast side of the island of Hawaii, with risk due to the active volcanic flank, and the sharp NW-SE discontinuity in eastern California. The latter case highlights the boundary between the Central Valley sediments to the west and Sierra Nevadan batholith to the east. Most of the risk in the Central Valley is from distant San Andreas events, the effects of which are filtered out by the predominantly hard igneous rocks of the Sierra Nevada.

Statewide loss costs are summarized in Figure 2, with the values normalized to the loss cost for California. These incorporate the relative distribution of population and residential construction within each state. California has by far the highest risk, at more than three times the relative risk on a statewide basis than Washington, the second highest. When the relative exposure is considered, California has about twenty times the annualized economic loss from earthquake as Washington and ten times that of the rest of the western states combined.

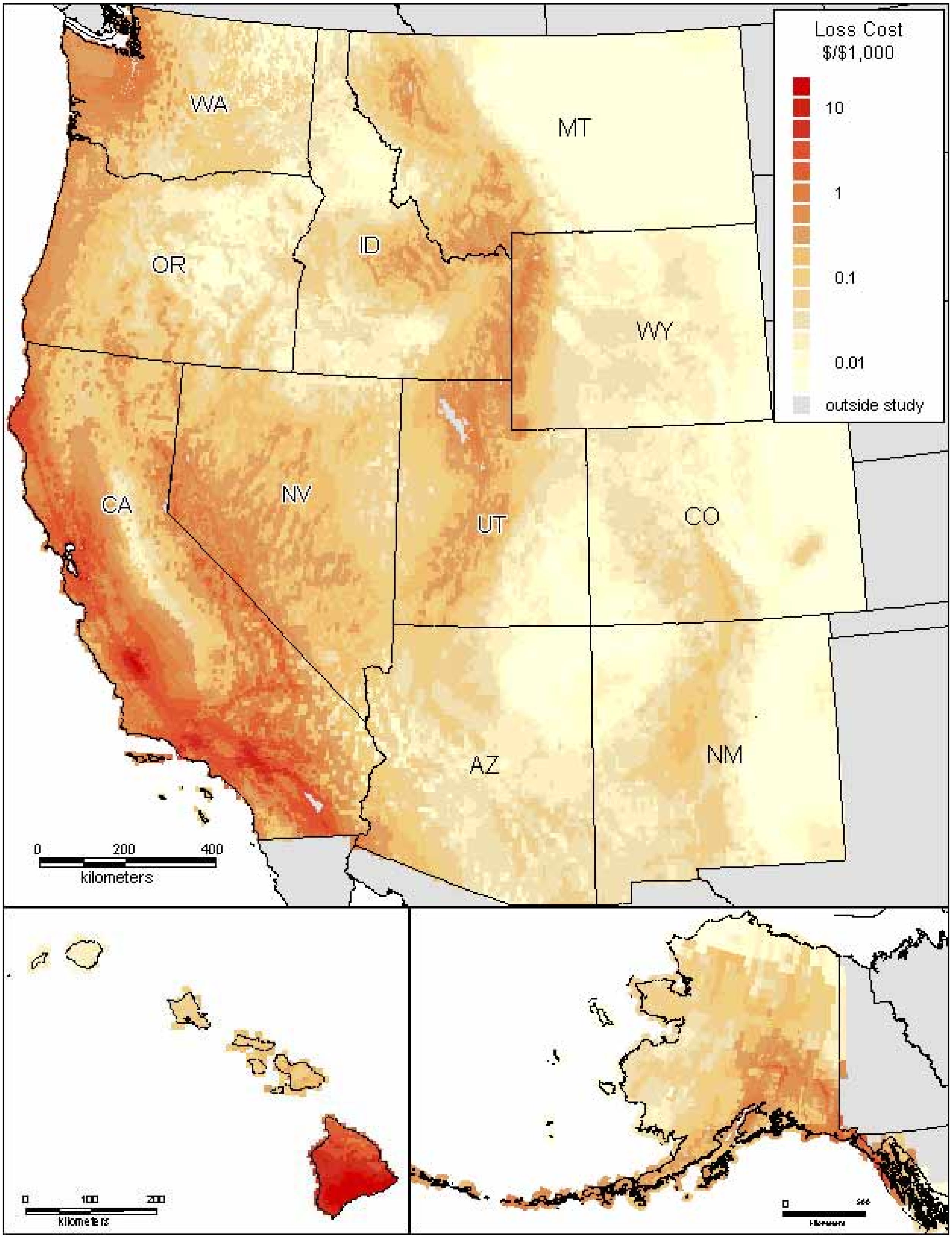

Figure 1. Average annual loss costs for residential construction in the western United States.

State	Abbrev	Population (2002 est)
California	CA	35,001,986
Washington	WA	6,067,060
Utah	UT	2,318,789
Alaska	AK	641,482
Nevada	NV	2,167,455
Hawaii	HI	1,240,663
Oregon	OR	3,520,355
Montana	MT	910,372
New Mexico	NM	1,852,044
Idaho	ID	1,343,124
Wyoming	WY	498,830
Arizona	AZ	5,441,125
Colorado	CO	4,501,051

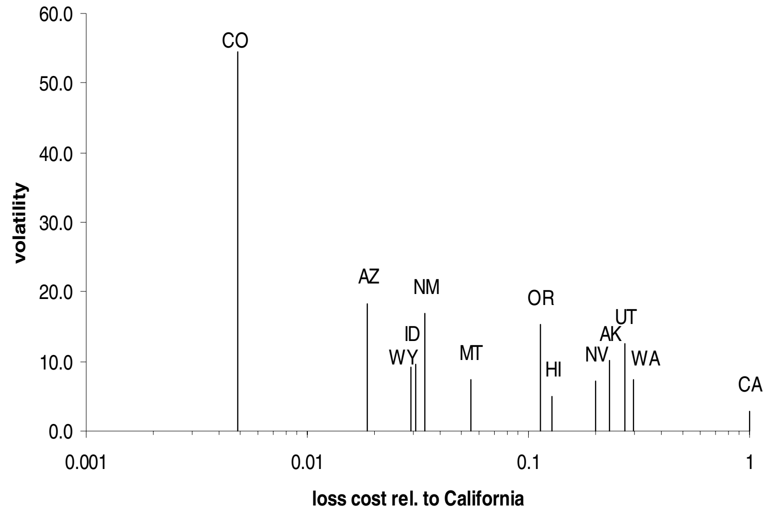

Figure 2. Statewide risk relative to California and volatility estimates.

The impact of exposure location relative to the hazard is evident. The states of Idaho, Montana, Utah, and Wyoming share the Intermountain Seismic Belt, the roughly N-S, arcuate band of hazard illustrated in the center of Figure 1. While the relative risk within this belt is similar, the only major city to fall in is Salt Lake City in Utah. Consequently, the statewide loss cost is 5-10 times greater in Utah than the other three states.

Figure 2 also includes a measure of the volatility of the annual loss. This is the coefficient of variation on the loss cost, reflecting the range in possible losses for any given year rather than uncertainty in the actual loss estimate. A comparison between Washington and Utah provides an illustrative example. The lost costs are similar between the two, but the volatility in Utah is much higher because the main contributors are rare but large losses from the Wasatch fault system. Washington, on the other hand, has a large contribution from the more frequent intraslab earthquakes (e.g. 1949, 1965, 2001), which historically have caused moderate damage. The high rates of occurrence on the island of Hawaii result in a relatively low loss volatility for the state, but the overall loss cost is moderated because over 70% of the state's populace live on the seismically quiet island of Oahu.

Impact of Insurance

Insurance is a mechanism for risk transfer in which the property owner pays a premium to another party for protection against some loss-causing event. The insured loss relative to economic is most significantly affected by penetration rate and predominant policy structures. Penetration rate refers to the proportion of property owners who choose to purchase insurance. The insurance policy is a contract defining the conditions for payout to the insured. It typically includes deductibles (proportion of loss the insured must absorb before the policy pays a claim) and limits (maximum amounts payable by the insurer). These may be defined for individual coverage types, the policy as a whole, or both.

The 1994 Northridge earthquake and 1992 Hurricane Andrew events provide contrasting examples of insured : economic loss relativities. The Northridge earthquake caused an estimated \$42 bn in economic loss, \$15 of which was insured [22, 23]. In contrast, \$16 bn of Hurricane Andrew's estimated \$30 bn economic loss was insured ([24, 25] adjusted to 2001\$ using [26]). The relative proportion was higher for Andrew for reasons of both penetration and policies. Homeowners are usually required by lenders to have fire insurance, and wind was covered as part of the standard policy at that time. Coverage for earthquake, on the other hand, must be purchased separately and thus a smaller fraction of structures were insured for Northridge. Earthquake deductibles are also much higher for earthquake, around 10% of the structure value at the time, while a typical wind deductible in Florida was $500.

Figure 3 provides an estimate of the fraction of the total residential loss cost that would be covered by insurance. (Note that this is the percentage of the average annual loss over all events, not the relativity one should expect for a single event.) The ratios of insured to economic loss are calculated from absolute average annual loss values and thus have a greater dependence on the exposure assumptions than the loss costs; relativities between states are less uncertain than the actual percentages. The per-event correlation in loss becomes more important once financial structures such as deductibles are considered. An earthquake with severe localized loss might have the same economic loss as an event with lesser losses spread out over a large area but, assuming constant deductibles, the latter event would generally have less insured loss because more policy deductibles would have to be exceeded.

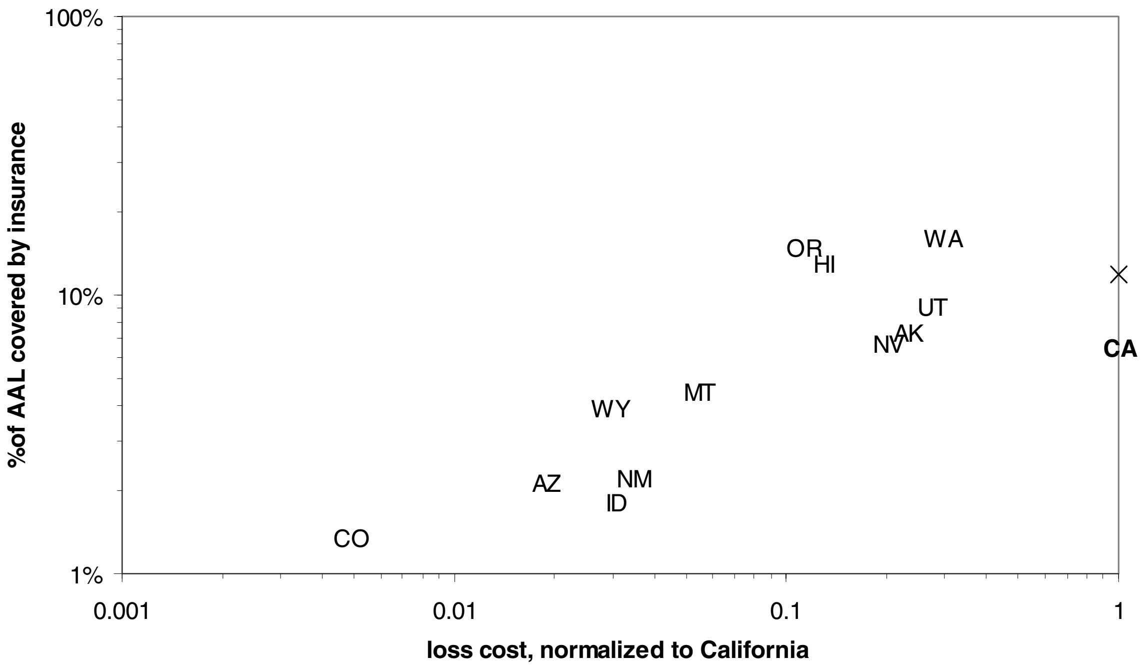

Figure 3. Modeled percentage of residential average annual loss per state covered by insurance. Abbreviations as per Figure 2, small 'x' is California commercial.

In general, percentage increases with the loss cost as there is some expectation that the rate of earthquake insurance takeup will increase in areas of higher risk. Deductibles tend to be higher as well, but the relativities are more sensitive to assumptions in penetration. The outlier in this analysis is California, where the current cost of homeowners' insurance relative to coverage has greatly reduced the fraction of earthquake losses borne by insurers. This is considered further in the Discussion below.

DISCUSSION

Factors influencing loss costs

Comparison of Figure 1 with USGS hazard maps of the area [1] supports an obvious observation: a primary source of local variations in the relative loss costs is the source model modified by local site conditions. At this scale, variations in the vulnerability data are largely overwhelmed by the hazard changes. The vulnerability would show much greater differentiation if additional construction or occupancy types were included for comparison, particularly for buildings of different heights. The performance-based approach used for damage calculation considers the ground motion spectrum, period-dependent site amplification, and structure period.

When considered in the aggregated context of a portfolio, the distribution of exposure relative to the hazard becomes more crucial in determining the loss cost. Los Angeles County has both high hazard from numerous active faults and absolute risk due to its large population, but its relative loss cost ranks lower because the population is split into several different urban areas [27, 28].

Average annual loss or loss cost is a useful metric for comparing risk but is a collapsed version of the full loss exceedance curve; in isolation it lacks detail on what kind of losses comprise the total. Environments with very frequent small losses versus rare catastrophic losses could generate the same AAL, but the latter presents a more problematic case for a homeowner or insurer.

The volatility measure shown in Figure 2 provides some idea of where a given state falls in the spectrum, with the previous example of Washington and Utah illustrating this point. Both have similar loss costs, with Utah showing a higher volatility. Consider three annual probability ranges, <0.2%, 0.2-1%, and >1%, nominally equivalent to return periods of >500 years, 100-500 years, and <100 years. The average annual loss for Washington splits approximately 25-35-40 across these ranges, reflecting the high contribution by frequent intraslab events. Utah, in contrast, splits 50-35-15 due to rare but catastrophic losses from Wasatch fault events.

A related point is that frequent events will contribute greatly to average annual loss, even if they do not generate large losses. California is the extreme case for short return period losses, with over 80% derived from the >1% probability portion of the loss curve.

Residential insurance in California

Neglecting epistemic changes from modeling, the relative loss costs discussed above are fairly constant risk metrics. The local seismic hazard may be impacted by time-dependent recurrence after a large event, but overall is driven by long-term tectonics and seismic moment budgets. Building vulnerability is gradually affected by code changes and new construction, but is another factor that changes slowly. What does change are insured loss estimates, as prevailing market conditions will drive changes to the insured proportion of value at risk. The 1994 Northridge earthquake was a seminal event in its influence on the US property insurance industry; much of the commentary in this section follows a recent report on the event [23].

Following the devastating losses incurred in the Northridge earthquake, insurers moved to better understand their risk from earthquakes and develop pricing and policy terms that reflected this risk. Insurance availability gradually returned to equilibrium on the commercial side, but residential lines experienced a crisis in the years following. Personal lines insurers are required to offer the option of earthquake insurance when selling homeowners' policies, and many insurers stopped writing insurance due to concerns that they would not be able to remain solvent if another similar event occurred. The compromise was the CEA (California Earthquake Authority), a government entity funded by insurers.

The CEA offers a "mini-policy" with a high deductible (15%) and limited coverage for contents and additional living expenses. Because it is perceived to be expensive relative to the coverage provided, many homeowners elected not to purchase a earthquake rider on their policy. Only about 17% of homeowners currently have earthquake insurance, down from 30-40% at the time of Northridge. The combination of higher deductibles and lower limits with fewer policyholders has reduced the proportion of losses that will be paid out by insurers. RMS model results suggest that insured residential losses from a repeat of the Northridge earthquake today would be 70% lower than those incurred in 1994.

The commercial market in California is less regulated than for personal lines and has continued to grow since 1994. An equivalent analysis of the insured annual loss for commercial lines yields almost twice the percentage covered as for residential lines; this commercial result is shown on Figure 3 with an 'x'. The residential markets are gradually adapting to fill the demand for earthquake coverage, as evidenced by the recent expansion of the CEA's product line to include policies with lower deductibles and increased coverage for contents and ALE.

CONCLUSIONS

We have presented relative seismic risk for thirteen western states on the basis of modeled results for residential exposure, illustrated in terms of average annual loss cost. Natural breaks in per-state results suggest four groups. California stands far above the rest in risk, a result borne out by historical experience and common sense. Ranked in order of decreasing risk, Washington, Utah, Alaska and Nevada comprise the next tier. Each have significant exposure close to active seismic sources. Hawaii and Oregon follow closely behind; both have locally high hazard, but the loci of population and exposure are not in the highest risk zones. There is a wide range in the last group, ordered from Montana, New Mexico, Idaho, Wyoming, Arizona, to Colorado.

Relativities in these loss cost results are similar to the absolute economic risk, but have been normalized to exposure and thus do not provide actual dollar losses. Washington is second in absolute loss to California, followed by Utah, Oregon, and Nevada. The remaining eight states in rank order are Hawaii, Alaska, Arizona, New Mexico, Montana, Idaho, Colorado, and Wyoming.

Insurance coverage of residential losses generally increases with the risk for the state, with California currently a notable exception. The impact of the Northridge earthquake is still being felt, but conditions are evolving in the insurance market that will eventually lessen the direct impact that would be borne by homeowners in the next major earthquake.

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