Pricing the Earthquake Exposure Using Modeling

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ABSTRACT

Catastrophe hazard modeling has become an important tool for ratemaking in lines of business subject to low frequency, high severity type losses. Natural hazard events such as hurricanes, tornadoes, and earthquakes rarely occur, but their devastation can be overwhelming when they do. Few insurance companies have enough historical loss data to sufficiently price for these events. In our paper, we plan to demonstrate a methodology which details the use of a model's output in determining a statewide rate level indication for the earthquake line of business, as well as a methodology for determining more equitable territorial relativities within a state.

Our paper will outline a practical and understandable methodology for dealing with some complex issues involved in pricing the earthquake insurance exposure. The emphasis of the methodology within our paper will be on practicality and potential regulatory acceptance. Another feature of our paper will be the inclusion of a section dealing with the reflection of the net cost of reinsurance in the proposed direct rates. A final consideration is the treatment of a model's output when it is believed the modeled results are less than fully credible.

The CAS ratemaking principles address data considerations used in making rates. Catastrophe hazard modeling output is an important component of "other relevant data" that is referred to in the principles [1]. A company's history of earthquake premiums and losses does not have sufficient predictive power for establishing adequate rates. Our paper will rely on the power of catastrophe hazard simulation of multiple possible events and the associated loss costs generated from these models.

Biography:

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INTRODUCTION

Pricing for an insurer's risk to hurricanes and earthquakes has never been an easy task. No insurer's loss history is adequate enough to cover the expectation of all possible type and size of events. Any ratemaking formula based on actual loss experience alone for such rare events will fail to capture the scope of possible events that could impact an insurer's financial results. Catastrophe hazard modeling represents a way of developing the scope of possible catastrophic events that can impact an insurer's book of business. The financial impact of these events is based on scientific evidence of the characteristics of the underlying peril and its interaction with the insured properties.

In this paper we will concentrate on the earthquake peril and its pricing. After an overview of earthquake modeling, we will discuss target underwriting profit provisions, reinsurance costs, and other components of developing an adequate rate per $1,000 of dwelling coverage for a typical book of Homeowners business. The credibility of the results will be addressed in the derivation of the indicated rates, along with partitioning of the state into geographic zones based on the relative difference in loss costs determined from the modeled results.

We will then discuss possible shortcomings inherent in modeling and suggest several solutions on how to handle these deficiencies in the derivation of an adequate rate. We will conclude the paper with a list of additional considerations that need further research, given the great uncertainty associated with any modeling process.

OVERVIEW OF EARTHQUAKE MODELING

Actuaries are relying more than ever on the use of modeling in accurately pricing catastrophic risks such as hurricanes and earthquakes. While we may not completely understand the intricacies of all functions and assumptions used in modeling, it is important nonetheless to present an overview of an earthquake computer simulation model. Appendix A describes the earthquake model developed by Applied Insurance Research (AIR) of Boston, Massachusetts.

The US earthquake model developed by AIR uses sophisticated mathematical techniques to estimate the probability distribution of losses resulting from earthquakes anywhere in the 48 contiguous states. The earthquake model is composed of three separate elements: an earthquake occurrence model, a shake damage model, and a fire-following model.

For ratemaking purposes, the output from the model will include loss costs applicable to a specific location, type of construction and policy form. Our interest is in a single-family dwelling as covered under a typical Homeowners policy. The loss costs generated by the AIR model are the basic building blocks in the development of an appropriate rate for this coverage. The next section will begin with those basic building blocks.

PROPOSED METHODOLOGY

The goal of this paper is to present a methodology for developing a rate per $1,000 of Earthquake coverage. We will assume that the indicated rate is based on Coverage A of a typical Homeowners single-family dwelling. That is, the modeled results include all coverages (including time element expenses), and the figures have been ratioed to Coverage A, in 1000's.

We begin with the statewide indicated rate as developed from the loss costs resulting from the model. Sections on the net cost of reinsurance and the target rate of return and proper underwriting profit provision follow. Territorial partitioning and the derivation of zone relativities conclude this section.

Statewide Indicated Rate

The statewide indicated rate is determined using the pure premium method. The first input into the methodology is the statewide modeled incurred losses stated at a base deductible level. In this example, the base deductible is 10% applicable to the dwelling limit. The annual expected losses represent the average annual amount of incurred losses an insurer could expect from writing the Earthquake line of business in State X if each insured had a 10% deductible. The modeled results are generally available on an individual state basis as well as on a zip code or county basis within the state. The annual expected losses are trended (severity only) and adjusted for LAE, then ratioed to the total trended value of insured dwellings to develop a projected pure premium which is used to determine the indicated rate as shown on Exhibit 1. (A viable alternative would be to trend the insured values first and use these trended values as input to the catastrophe model, thus yielding an estimate of trended severity within the model results). In this example, the current rate is assumed to be $2.50 per $1,000 of dwelling coverage. The indicated rate is calculated by taking the projected pure premium and grossing it up to include reinsurance costs, trended fixed expenses, and variable expenses. After completing these calculations, the indicated rate is $3.77 per $1,000 of coverage.

Exhibit 1
Sheet 1

STATEWIDE INDICATED RATE

(1)	Modeled Incurred Losses at a 10% Deductible as of 12/31/95:	\$19,500,000
(2)	Total Dwelling Coverage as of 12/31/95:	10,965,281,000
(3)	Proposed Effective Date:	7/1/96
(4)	LAE Factor:	1.150
(5)	Loss Trend Factor Trended to 7/1/97:	1.250
(6)	Exposure Trend Factor Trended to 7/1/97:	1.190
(7)	State X Earthquake Share of Expected Net Cost of Reinsurance:	\$7,592,703
(8)	Trended Fixed Expense Provision Per \$1000 of Coverage:	0.265
(9)	Pure Premium Per \$1000 of Coverage: $\left\{\{\{[(1) \times (4) \times (5)]+(7)\} \times 1000\} / [(2) \times (6)]\right\} + (8)$	\$ 2.99
(10)	Variable Permissible Loss and LAE Ratio:	0.794
(11)	Indicated Rate: (9)/(10)	\$3.77
(12)	Current Statewide Rate Per \$1000 of Dwelling Coverage:	\$2.50
(13)	Indicated Percentage Change: (11) / (12) - 1	50.8%
(14)	Proposed Change:	50.8%
(15)	Proposed Statewide Rate: (12) x [1 + (14)]	\$3.77

Exhibit 1
Sheet 2

STATEWIDE INDICATED RATE
EXPLANATORY NOTES

(1) This is the main output received from the modeling firm. It is an estimate of the annual expected losses at a base deductible for an insurer, given the current book of business within the state for the Earthquake line of business.

(2) The total value of insured dwellings is provided to the modeling firm by the insurer and is used to determine the average annual expected losses per $1,000 of coverage in the pure premium method.

(3) The proposed effective date as selected by the insurer.

(4) The LAE factor is calculated based on a comparison of estimated ultimate loss adjustment expenses to estimated ultimate losses from the most recent earthquake events faced by the insurer.

(5) The modeled losses are trended using historical Homeowners severity data. Earthquake loss trend data is not used because of its instability. Losses should not be trended for frequency, unless the insurer is confident there exists an increased period of seismicity in the future.

(6) The exposure trend is based on historical changes in the average amount of insurance for the Earthquake line of business.

(7) The State X Earthquake share of the expected net cost of reinsurance is calculated as described on Exhibit 2.

(8) The trended fixed expense provision per $1,000 of coverage is calculated by trending fixed expenses to a point in time appropriate for the proposed effective date and ratioing it to trended insured value using an annualized fixed expense trend of 5%.

(9) The formula combines the modeled incurred losses with the net cost of reinsurance for the state and line of business with the trended fixed expense provision to provide an estimate of the projected pure premium to be expected during the time the proposed rates are to be in effect.

(10) The variable permissible loss and LAE ratio is calculated based on historical variable expenses and a consideration of the relative riskiness of the Earthquake line of business compared to other lines being written and the overall required return on surplus. An 18.2% underwriting profit provision was used along with 2.4% provision for variable expenses.

Net Cost of Reinsurance

An important component which we reflected in the rate indication is the net cost of reinsurance. An insurer should decide whether to include this component based on the costs and anticipated recoveries associated with its reinsurance program. This component should be included as a cost if the expected reinsurance recovery is less than the amount of premium paid to the reinsurer for reinsurance protection. This relationship will generally be the case due to the presence of transaction costs which include a margin for reinsurance risk load and profit. The expected reinsurance recovery represents the average annual amount an insurer could expect to recover from the reinsurer(s) due to insured events and can be determined using catastrophe modeling. The expected reinsurance recovery needs to be calculated considering the attachment points or quota share percentages associated with an insurer's reinsurance program. Most often, an insurer's reinsurance program is structured to provide protection against many types of hazards; however, some reinsurance contracts are designed to provide protection against only one hazard. To accurately measure the net cost of reinsurance for a particular hazard, the reinsurance premium from all programs which provide protection for the hazard should be included. If other catastrophic hazards such as hurricanes are a large proportion of an insurer's exposure to catastrophe loss, the reinsurance premium for multi-hazard contracts could be segregated for each hazard. The reinsurance premium for each hazard could then be included with each net cost of reinsurance calculation for every line of business. In the example, however, the net cost of reinsurance is allocated to the Earthquake line of business and then the appropriate state. The allocation to line of business in our example as shown on Exhibit 2 was based on model results by comparing expected Earthquake reinsurance recovery to the total expected reinsurance recovery. This ratio was applied to the net cost of reinsurance to obtain the earthquake-only net cost of reinsurance. The allocation to a state level was done using written premium. It is important to note that this allocation may introduce a distortion if the state in question has a different level of premium adequacy than the countrywide premium adequacy.

Exhibit 2
Sheet 1

ESTIMATED NET COST OF REINSURANCE

(1)	1995 Countrywide Reinsurance Premium for Contracts covering the Earthquake peril:	$37,890,000
(2)	Expected Reinsurance Recovery:	$17,481,970
(3)	Net Cost of Reinsurance: (1) - (2)	$20,408,030
(4)	Expected Earthquake Reinsurance Recovery:	$ 9,154,600
(5)	Proportion of Earthquake Recovery to Total Recovery: (4) /(2)	52.4%
(6)	Earthquake Share of Net Cost of Reinsurance: (3) x (5)	$10,693,808
(7)	1995 State X Earthquake Written Premium:	$27,271,677
(8)	1995 Countrywide Earthquake Written Premium:	$38,551,154
(9)	State X Earthquake Share of Net Cost of Reinsurance: [(7) /(8)] x (6)	$ 7,592,703

Exhibit 2
Sheet 2

NET COST OF REINSURANCE
EXPLANATORY NOTES

(1) This is the total of all reinsurance premium paid for reinsurance contracts which provide protection for earthquake losses.

(2) This is a model output number. It is determined based on the attachment point or quota share arrangement an insurer has with its reinsurer(s).

(3) The net cost of reinsurance is the difference between the reinsurance premium paid for contracts providing earthquake protection and the expected total reinsurance recovery.

(4) Model results are used to determine what portion of the expected recovery is due to earthquake.

(5) The Earthquake proportion of the total expected reinsurance recovery is expressed as a factor to be applied to the total net cost of reinsurance.

(6) The Earthquake share of the net cost of reinsurance is the proportion of the earthquake recovery to the total recovery multiplied by the total net cost of reinsurance.

(7) The latest year State X Earthquake written premium is used to allocate the Earthquake share of the net cost of reinsurance to a state level.

(8) The latest year countrywide Earthquake written premium is used to determine what proportion of the countrywide Earthquake written premium is represented by State X.

The concept of including the net cost of reinsurance in a rate indication is relatively new and will likely be challenged or subjected to additional scrutiny by regulatory agencies. However, it does represent a cost of doing business, and therefore, we have chosen to include its net costs. Reinsurance costs could also be considered in conjunction with the selected rate of return and that discussion follows.

Target Rate of Return

For purposes of developing an underwriting profit provision, we have chosen a total rate of return methodology. We are not proposing one method over another, but we have selected this particular one for the development of a reasonable profit target for the Earthquake line of business. The target rate of return on GAAP equity is developed using a Discounted Cash Flow (Dividend Yield) Method and the Capital Asset Pricing Model (CAPM). The selected rate of return, averaged from the results of these two methods, is 13.0%. From this selected rate of return we have subtracted 8.0%, which represents the post-tax investment rate of return from all investable funds. Exhibit 3 converts this difference to a pre-tax basis, using a corporate tax rate of 35%. For an insurer's total book of business this percentage is then divided by the company's premium-to-surplus ratio in order to convert the target underwriting profit provision to a percentage of premium. Although we do not endorse the divisibility of surplus or leverage ratios, we are proposing this method for calculating a reasonable Earthquake underwriting profit provision.

We have selected a company whose underwriting results resemble the years 1985-1994 for all Property and Casualty insurers writing Personal Lines Automobile, Homeowners Multi-Peril, and Earthquake coverages. (It would be appropriate for more years to be used; however, the Earthquake line of business was not segregated prior to 1985). The data can be found in Best's Aggregate and Averages, 1995 edition [2]. A company's own data can be used for this purpose as well.

Exhibit 3

TARGET UNDERWRITING PROFIT PROVISION

A. Target Rate of Return
(% of GAAP Surplus)

1. Dividend Yield Model	12.0%
2. Capital Asset Pricing Model	14.0%
3. Selected Target Rate of Return	13.0%

B. Target Underwriting Rate of Return
(% of GAAP Surplus)

1. Investment Rate of Return After Tax	8.0%
2. Target U/W Return After Tax (A3) - (B1)	5.0%
3. Target U/W Return Before Tax (B2)/(1 - 0.35)	7.7%

C. Target Underwriting Profit Provision
(% of Direct Earned Premium)

1. Net Written Premium/GAAP Surplus Ratio	1.30
2. Indicated U/W Profit Provision (B3) / (C1)	5.9%
3. Selected U/W Profit Provision	5.9%

Note: A select group of insurers were chosen that resemble the mix of business written by the filing insurer. Company betas and projected dividend yields were taken from Value Line. Both the Dividend Yield Method and the Capital Asset Pricing Model were used in determining an appropriate rate of return. The selected target rate of return is a straight average of the two methods.

Basically, a company's underwriting profit provision should vary based on the riskiness of the line of business. A measure of risk we have chosen is the coefficient of variation (measured as standard deviation/mean, σ/μ) of a series of underwriting results for each line. Since the selected period includes the effects of Hurricane Andrew and the Northridge Earthquake, we adjusted the losses so that Andrew reflects a 1-in-30 year event and Northridge a 1-in-50 year event. We did not adjust for Hurricane Hugo, although one could argue for that adjustment as well. Table 1 shows the yearly (1985-1994) underwriting gains/losses as a percent of net earned premium.

Table 1
Underwriting Results as a Percentage of Premium

Year	Private Passenger Automobile	Homeowners Multi-Peril	Earthquake
1985	-11.0%	-11.7%	60.0%
1986	- 8.3%	-3.5%	58.0%
1987	-6.0%	3.3%	44.2%
1988	-6.8%	0.0%	57.5%
1989	-8.9%	-13.9%	-42.1%
1990	-9.1%	-12.9%	43.8%
1991	-4.6%	-17.7%	55.3%
1992	-1.9%	-58.4%	61.4%
1993	-1.8%	-13.5%	68.0%
1994	-1.3%	-18.4%	-222.2%

Table 2 shows the coefficient of variation of each line, the weighted average of the CVs using the latest ten years of premium, and what we are labeling as a risk index, which is the ratio of each line's CV to the weighted CV.

Table 2

Line of Business	Premium Distribution	Coefficient of Variation*	Risk Index
Private Passenger Automobile	80.1%	0.550	0.92
Earthquake	0.5%	1.854	3.09
Homeowners Multi-peril	19.4%	0.780	1.30
Total	100.0%	0.600	1.00

* Absolute Value

Assume the company's premium-to-surplus ratio corresponds to the industry's at 1.30, so that its inverse is .77. The risk indices are used to adjust each line's surplus ratio (surplus-to-premium) in the total rate of return methodology, resulting in target underwriting profit provisions which reflect the risk of each line of business. The resulting Earthquake profit provision will be used in the derivation of the variable permissible loss and loss adjustment expense provision to follow later. Table 3 summarizes this information.

Table 3

Line of Business	Risk Index	Implied Surplus Ratio (S/P)	Target Underwriting Profit Provision
Private Passenger Automobile	0.92	0.71	5.4%
Earthquake	3.09	2.38	18.2%
Homeowners Multi-peril	1.30	1.00	7.7%
Total	1.00	0.77	5.9%

In this example, industry net underwriting results were used to determine an appropriate underwriting profit provision for the Earthquake line of business. A larger Earthquake underwriting profit provision would probably be obtained if direct results were used instead. This is due to net underwriting results having variability stripped off by the stabilization of reinsurance. Using our methodology, it is reasonable to conclude that part of the difference between underwriting profit provisions calculated using net or direct underwriting results would be due to reinsurance costs. An insurer should expect a lower net cost of reinsurance if part of the reinsurance cost is reflected in the Earthquake underwriting profit provision calculated using direct underwriting results. Efforts could be made to quantify what portion of the net cost of reinsurance is contained in an Earthquake underwriting profit provision based on direct underwriting results. One possible approach would be to compare the difference in Earthquake underwriting profit provisions calculated using net and direct underwriting results to a net cost of reinsurance as calculated in this example.

Zone Relativities

Model results can also be used to determine revised Earthquake zone definitions and Earthquake zone relativities. The data used to establish Earthquake zone definitions are model results at a five-digit zip code level. The sum of all the five-digit zip code modeled losses and dwelling insured values should balance to the statewide totals used to determine the statewide indicated rate. In the example, we are assuming the state is comprised of twenty distinct five-digit zip codes. The data on Exhibit 4 shows the data segregated by five-digit zip code. We used a SAS clustering program to determine the new Earthquake zone definitions and zone relativities. The following is a description of the SAS procedure we used as described in the SAS user's manual [2].

PROCFASTCLUS performs a joint cluster analysis on the basis of Euclidean distances computed from one or more quantitative variables. The observations are divided into clusters such that every observation belongs to one and only one cluster. The procedure is intended for use with large data sets, from approximately 100 to 100,000 observations. With small data sets, the results may be highly sensitive to the order of the observations in the data set.

PROCFASTCLUS uses a method referred to as nearest centroid sorting. A set of points called cluster seeds is selected as a first guess of the means of the clusters. Each observation is assigned to the nearest seed to form temporary clusters. The seeds are then replaced by the means of the temporary cluster, and the process is repeated until no further changes occur in the cluster.

After specifying the desired number of Earthquake zones, and using the SAS procedure, we obtained the results in Exhibit 5. The number of zones to be used in a real application will depend on the size of the insurer's Earthquake book of business, geographic spread, and the level of seismic variation that exists within the state. It is important to note that the proposed Earthquake zones will probably not be contiguous because five-digit zip codes from different parts of the state will very often fall into the same cluster in the SAS procedure. We only used twenty zip codes in our example; however, the SAS procedure has the capability to handle a much larger number of zip codes. The relativities shown in Exhibit 5 are applied to the statewide indicated rate previously calculated to determine each zone's Earthquake rate.

The resultant earthquake zone rates should probably display a wider variance, since it could be argued that risk margins should vary by geographic location for the earthquake peril. We view this as another area deserving further consideration and an important aspect of determining adequate earthquake rates.

Exhibit 4

STATE X
EARTHQUAKE MODEL RESULTS
ZIP CODE LEVEL

Five-digit Zip Code Area	Dwelling Insured Value (in $000)	Expected Annual Loss at a 10% Deductible	Loss Cost
1	$ 921,339	$ 2,303,348	$ 2.50
2	1,096,528	1,644,792	1.50
3	258,481	387,722	1.50
4	548,264	603,090	1.10
5	922,272	830,045	0.90
6	79,839	98,897	1.24
7	722,114	902,643	1.25
8	103,211	232,225	2.25
9	803,112	3,011,670	3.75
10	801,247	721,122	0.90
11	552,322	359,009	0.65
12	402,178	623.376	1.55
13	700,659	1,156,087	1.65
14	1,102,321	2,369,990	2.15
15	200,321	490,786	2.45
16	402,111	1,105,805	2.75
17	727,727	1,928,477	2.65
18	202,001	490,786	1.03
19	112,007	123,768	1.11
20	307,227	399,088	1.30
Total	$ 10,965,281	$ 19,500,000	$ 1.78

Exhibit 5

STATE X
EARTHQUAKE ZONE RELATIVITIES

Earthquake Zone	Total Dwelling Insured Value (in $000) (1)	Expected Annual Loss at 10% Deductible (2)	Loss Cost (3)	Indicated Relativity to Statewide (4)	Indicated Earthquake Zone Rate (5)
1	$ 552,322	$ 359,009	$ 0.65	0.37	$ 1.38
2	3,694,971	3,886,713	1.05	0.59	2.23
3	3,560,167	6,181,967	1.74	0.98	3.68
4	2,354,709	6,060,641	2.57	1.45	5.46
5	803,112	3,011,670	3.75	2.11	7.95
Statewide	$ 10,965,281	$ 19,500,000	$ 1.78	1.00	$ 3.77

Note: (3) = (2)/(1)
(4) = (3)/1.78
(5) = (4) x 3.77

SHORTCOMINGS INHERENT IN MODELING

Modeled results fall short of expected values for many reasons, most of which can be attributed to company issues or to adjustments not made within the models themselves. First, we will discuss company shortcomings, then follow-up with model shortcomings.
Where appropriate, we will make suggestions on how to handle quantifiable and supportable adjustments to the modeled input or output. The following list is not meant to be exhaustive, but is typical of company issues. Company shortcomings include:

1. Underinsurance (homes not insured to value) or overinsurance.
2. Demand surge for labor and materials after a large catastrophic event.
3. The need for extra claims adjusters following large events.
4. No data collecting or coding for retrofitting safety features.
5. Invalid or incomplete data.

The major company shortcoming may well rest on the problem of underinsurance. Expected loss to a particular structure in a particular area is based on applying an average damage ratio (defined as the ratio of the repair cost of a building to its total replacement value) to the total insured value of the structure. It is assumed then that the insured value of a building represents its true replacement cost. A company would do well to estimate its underinsurance (or overinsurance) problem before providing data to a modeling firm. If, on average, it is determined that a book of business is underinsured by 10%, then all limits should be adjusted before the model is run.

The effects of demand surge can be quite significant and should be factored into all modeled results. (It is not clear to us whether this adjustment should be made by the insurer or by the modeler.) Obviously, the demand for labor and materials will vary depending on the location and magnitude of each earthquake. The additional cost probably varies between 0% and 30%, but the highest demand is associated with events that have the lowest expected probability; therefore, the effect on average annual aggregate losses should be minimal. We believe this adjustment to the modeled loss costs is important, yet is an uncertain aspect of the process. Studies should be conducted to determine the impact of demand surge factors, perhaps by studying the payout of events such as Loma Prieta and Northridge, if the data is available. Either overall average demand surge factors should be applied to the resultant loss costs, or variable demand surge factors should be determined and applied by location and event.

The need for independent claims adjusters is a very real cost of settling claims following large catastrophic events. It is not clear which loss adjustment expense (LAE) factors should be applied to the modeled expected loss costs. There has simply not been enough loss experience to determine appropriate factors. We suggest using either the ratio of LAE to losses of past events (which may understate the true ratio) or simply use the underlying policy average LAE factor, given Earthquake coverages are normally endorsed to a Homeowners or Dwelling Fire program.

Modeled results should account for retrofitting safety features of an insured structure. Average damage ratios should be adjusted for these features. It is not clear to us how their effects can be measured, but research should be conducted and insurers should encourage their installation. A strongly built and reinforced home should surely withstand the initial impact and aftershocks of an earthquake, as opposed to a home whose frame is not bolted to the foundation, for example. Most insurance companies probably do not request information on retrofitting mechanisms, nor do they store the data. We would encourage the Insurance Institute for Property Loss Reduction to study the effects of such safety features and simulate an earthquake under monitored laboratory conditions to determine the extent of damage on the structure and its contents.

Finally, there is always the possibility of invalid data, incomplete data, or no data at all. Invalid data is most prominent if zip code, county, or street address is not validated before being stored on the insurer's database. Either the data should be cleaned up before the input files are created, or the data should be eliminated from analysis. Most companies do not have enough insureds located in all areas of the state. Therefore, there will be many locations with no modeled loss costs. In these situations, modeling firms have access to an inventory of typical building structures by location: average dwelling limit, type of construction, average year of construction, building height, etc. Modeled loss costs from this "generic" inventory can supplement an insurer's results where few or no insureds reside.

There will also be locations with insufficient data. Assume for a moment that an insurer's book of business is mapped to the geographic zip code centroid of each zip code within the state. Although modeled results are assumed to be 100% credible by location, the reader could obviously question whether one, ten, or even one hundred exposures are enough to deem the results credible. An insurer's database could be complemented with the results of the generic inventory. The authors have chosen to consider data 100% credible by zip code with more than 100 exposures; otherwise, the generic inventory is given full credibility.

We now turn to shortcomings in the models themselves. These brief remarks are not intended to criticize any model or modeler, but to highlight the importance of their impact on modeled results. The following list is also not meant to be exhaustive, but does represent typical shortcomings.

1. Factor for unknown faults.
2. Inclusion of debris removal expenses.
3. Effects of aftershocks.
4. Parameter risk within the model.

The 1994 Northridge earthquake is a perfect example of an unknown fault, a blind thrust fault which does not break the earth's surface. Not even seismologists know the extent of undiscovered fault lines beneath the earth's surface. How understated could the modeled results be? No one knows for sure, and we propose no solution to handle this uncertainty. Although the models account for possible earthquakes in all historical seismic source zones, it is highly questionable if distributions in the model account for all potential seismicity. With the passage of time and advanced technology, perhaps some day these models will account for all possible faults. For now we will have to assume that a model's results may understate expected average annual losses, and hence, expected loss costs per $1,000 of coverage.

Debris removal expenses, although small, should be added to the model's expected loss costs. More prominent would be the effects of aftershocks which follow moderate to large earthquakes. Oftentimes, claims are reopened months later due to weakened structures repeatedly damaged from aftershocks. Future modifications to catastrophe models should account for this possibility.

Since catastrophe modeling is based on incomplete distributions developed from historical information, there will always exist parameter risk. This risk may lead to gross understatement (or overstatement) of potential insured losses, and as such, represents a potential shortcoming of modeling.

ADDITIONAL CONSIDERATIONS

There will always exist areas that deserve further consideration. While we have presented a practical procedure for developing adequate earthquake rates, some areas deserve additional research and attention. We will divide these topics into four categories: (1) shortcomings of models, (2) credibility of data, (3) necessary target rate of return, and (4) net reinsurance costs.

We devoted an entire section of this paper to model shortcomings and company data issues. We only repeat them here to emphasize their importance and need for further study. The cooperation of the insurance industry, modeling firms, and the IIPLR is necessary in order to quantify the impact of outstanding issues on expected loss costs. Perhaps special data calls or cooperative studies can be conducted and the results shared with all interested parties.

Computer modeling simulates thousands of possible events, and as such, its results are generally considered fully credible. The earthquake peril is so unique by location, especially in California, so there really does not exist a feasible complement of credibility to augment a local result. Perhaps a regional complement could be used, but its applicability is questionable, given local soil conditions and proximity to fault lines. We choose to believe that an industry inventory database represents the best alternative for a complement.

Insuring the Earthquake peril is much riskier than insuring Auto physical damage coverages. Due to the relationship between risk and return, a higher rate of return, and therefore, a higher underwriting profit and contingency provision, should be allowed to cover a company's earthquake exposure. As mentioned earlier, this provision should probably vary by location as well. We have presented a simplified method for deriving a reasonable profit provision, but we encourage more research in this important area.

Debate exists as to whether rates should include the costs of reinsurance on an insurer's book of business. After all, their inclusion could be viewed as a pass-through to the consumer. Also, in the long-run, neither the insurer nor the reinsurer(s) should be worse off for engaging in a reinsurance program; otherwise, neither party would enter into the contract. However, in the short-run, reinsurance costs are a legitimate expense of doing business, and we believe that all parties should share in that expense, including policyholders. Indeed, policyholders benefit from financially strong companies.

SUMMARY

Catastrophe hazard modeling has become an integral part of the ratemaking process. Actuarial ratemaking principles [1] state that "other relevant data may supplement historical experience. These other data may be external to the company or to the insurance industry ...". We have entered the realm of that other relevant data. Actuarial Standard of Practice (SOP) No. 9 [4] states that "an actuary should take reasonable steps to ensure that an actuarial work product is presented fairly ... if it describes the data, material assumptions, methods, and material changes in these with sufficient clarity that another actuary practicing in the same field could make an appraisal of the reasonableness and the validity of the report." However, with the advent of modeling the actuary must rely on the work of another person. SOP No. 9 continues by stating that "reliance on another person means using that person's work without assuming responsibility therefore." These other persons now include experts in the fields of geology, seismology, and structural engineering, just to name a few. Actuaries, however, can play a key role in contributing to the development of the models, and more importantly, the interpretation and communication of their valuable results.

Catastrophe hazard modeling has become a necessary tool for the adequate pricing of large catastrophic events such as hurricanes and earthquakes. Their frequency is so low and their severity so potentially high that not even all of the property and casualty companies in a state could have enough loss history upon which to base rates. Despite any shortcomings models may have, they hold the key to the future and the pricing of nature's perilous attacks.

REFERENCES

[1] Casualty Actuarial Society, "Statement of Principles Regarding Property and Casualty Insurance Ratemaking," as adopted May, 1988.

[2] Best's Aggregates & Averages, Property-Casualty United States, 1995 Edition, A.M. Best Company, Inc., pp. 174,176.

[3] SAS/STAT® User's Guide, Version 6, Fourth Edition, Volume 1, Cary, NC: 1989, Copyright® SAS Institute Inc. pp. 823-824.

[4] Actuarial Standards Board, "Documentation and Disclosure in Property and Casualty Insurance Ratemaking, Loss Reserving, and Valuations," as adopted January, 1991.

APPENDIX A

The model developed by Applied Insurance Research uses sophisticated mathematical techniques to estimate the probability distribution of losses resulting from earthquakes anywhere in the 48 contiguous states. The earthquake model is composed of three separate elements: an earthquake occurrence model, a shake damage model, and a fire-following model. The earthquake occurrence portion of the model uses a probabilistic simulation to generate a synthetic catalog of earthquake events that is consistent with the historical record. The shake damage estimation portion of the model uses analytical numerical techniques to calculate the distribution of losses for individual buildings given the characteristics of the event. The fire-following portion of the model uses simulation to estimate fire losses following an earthquake. Together these techniques allow the estimation of a wide range of information about potential earthquake losses in the United States. The earthquake simulation model incorporates statistical descriptions of a large number of variables which define both the originating event (the earthquake) and its effect on structures. Some of these variables are defined probabilistically, and some deterministically. This section will describe the key components of the model, the main variables affecting the outcomes, and the relationships between the primary variables.

The model is described in the following sections:

- Earthquake occurrence
- Attenuation
- Exposure characterization
- Shake damage estimation
- Fire-following loss estimation

Earthquake Occurrence

For earthquakes there are three key types of variables that describe the physical phenomenon. In broad terms, these variables describe (1) where earthquakes can occur, (2) the size of the earthquake, and (3) the likelihood of seeing an earthquake of a particular size. In other words, the variables describe where, how big, and how often earthquakes occur.

The issue of where earthquakes occur is handled by identifying *faults* or *seismic zones* where historical earthquakes have been observed. On the west coast earthquakes tend to occur along well defined geological features called faults, which are places where the surface of the earth has been ruptured by past earthquakes, and which are observable at the ground surface or by subsurface sounding techniques. Not all faults are active, which is to say that not all faults are believed capable of rupturing in the present, although they have ruptured in the distant past. Where faults are observed, and where the historical catalog of earthquakes indicate that the faults are still capable of rupturing, the surface trace of the fault defines a possible location for future earthquakes.

Not all earthquakes occur on identifiable faults, however. Many earthquakes, especially those east of the Rocky Mountains, occur on faults that are not visible at the surface. Such faults are inferred from the occurrence of earthquakes in the historical record. For these areas, a source zone is created, which is an area with fuzzy boundaries within which future earthquakes are possible.

The AIR model contains approximately 250 seismic source zones covering the 48 contiguous states. Each source zone is defined by a line on the surface of the earth with probability distributions describing the variability of potential epicenters both along and perpendicular to that line. Hence a potential earthquake is not limited to occur along a known fault line, but can with some probability occur anywhere in the vicinity of a fault, or anywhere within a seismic source zone, depending on the degree of uncertainty associated with the historical record of earthquakes in that area. The central line of the source zone does define the dominant direction of faults in the area and characterizes the orientation of the rupture surface.

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The size of an earthquake is usually measured by one of several *magnitude* scales. In the AIR model, the surface wave magnitude M_s scale is used to characterize the earthquake magnitude. For every fault and source zone, the frequency of earthquakes of different magnitudes must be described. Seismologists generally agree that, over a considerable magnitude range, the logarithm of the number of historic earthquakes that exceed a given magnitude scales linearly with magnitude. This indicates that the frequency-magnitude relationship is approximately exponential. Additionally, paleo-seismologic data have been interpreted by some researchers to indicate that the frequency-magnitude relationship for large earthquakes differs from exponential scaling, leading to the notion of characteristic earthquakes in certain geographic areas. The AIR Model incorporates a truncated exponential distribution, or truncated "Gutenberg-Richter" relationship, to represent potential seismicity in each source zone. Where appropriate we additionally incorporate a characteristic earthquake model.

The AIR earthquake model is calibrated to a catalog of historical earthquakes which is as complete as possible, and which covers the historical record from the mid-1600's to the present. Because the completeness of the catalog varies both in time and as a function of magnitude (larger earthquakes are more likely to be included in the historical record), the fitting of the frequency-magnitude distribution is adjusted to account for the variation in historical completeness.

Earthquake Attenuation

After earthquakes are simulated using the probability distributions of the different earthquake parameters, the shaking intensity of the earthquake at every location affected by the earthquake is calculated using a relationship called an attenuation function. The local intensity is then corrected to reflect local soil conditions, as some types of soil amplify the shaking intensity relative to other soil types. This section discusses the variable interrelationships required to calculate the local shaking intensity.

From the characteristics of the earthquake, the local shaking intensity is calculated using an attenuation relationship. The attenuation relationship depends on the location of the source zone, as earthquake shaking attenuates more quickly in the western U.S. than in the eastern part of the country. That is to say that the same magnitude earthquake will affect a smaller area in California than in the northeast.

The attenuation calculation starts by spreading the energy released by the earthquake over the rupture surface, and integrating over the entire rupture surface to calculate the total effect of the earthquake. In effect, energy is assumed to be released uniformly over the rupture, and each incremental piece of energy is separately attenuated to obtain the effect at some distant point. This results in contours of equal intensity that are elongated along the orientation of the rupture.

The calculation of local shaking intensity itself consists of two parts. First, a basic intensity is calculated that assumes uniform soil conditions at every location. This intensity (called a Rossi-Forel intensity) depends on the distance of the site from the earthquake rupture, the orientation of the rupture, and the earthquake magnitude and focal depth. The rupture length is calculated from the basic earthquake parameters. Second, the Rossi-Forel intensity is modified to reflect the soil conditions at the site. Soil conditions for the entire country are digitized on grids varying from 0.1 degree latitude/longitude squares to 0.5 minute latitude/longitude squares. The local soil condition can significantly affect shaking intensity. The final intensity is identified as a Modified Mercalli Intensity (MMI).

The MMI is a generally accepted unit of shaking intensity that has had wide adoption for many years. It describes, in general terms, the type of damage that might be expected to buildings of usual design, and other effects of earthquakes that would be expected at that location. As such, the MMI is a good metric for estimating damages to structures.

Exposure Characterization

In order to calculate damages from an earthquake, the AIR model incorporates an extensive description both of the structural characteristics of an exposure and of the policy conditions describing the treatment of deductibles and other factors.

The seismic performance of a building depends primarily on the structural system resisting the lateral loads, but is also affected by other factors, including, in the AIR model, the age of the building and the height of the building. The age of the building is used to determine the likely code provisions under which the building was designed and constructed. Newer buildings, which may have been built to more exacting code provisions for seismic performance, are usually expected to perform better than older buildings.

The AIR model incorporates damageability relationships for many different classes of exposures, with up to three height categories in each class. In all, there are 42 different damage relationships for each coverage type, plus several different age categories. The categories of structural types are based in part on the structural types defined in ATC-13 (Applied Technology Council, 13-member advisory project engineering panel established in 1982 to develop earthquake damage/loss estimates for facilities in California), although the actual damage relationships are modified and extended well beyond those covered in that reference.

The exposures are characterized by policy limits for four different coverages: A, building applied to the total loss or to the loss from Coverages A, B, and C. Most commonly, Coverage B is combined with Coverage A for calculation purposes, and is assumed to apply to the same structural type as coverage A. The policy limit for each coverage may be defined by both a replacement value and a policy limit. This is because the replacement value may rise in time without the policy limit being adjusted to reflect inflation. Damage is always calculated with respect to replacement value, and then is capped at the policy limit if appropriate.

The location of the risk can be defined by a latitude and longitude point or by the five digit zip code in which the risk is located. The risk can also be associated with a line of business (homeowners, renters, commercial multi-peril, etc.) in order to report losses separately in categories meaningful to the insurer.

Damage Estimation

Given the local shaking intensity in MMI units, damages to structures at that location can be calculated if sufficient information is available about the structure. Two types of damage are calculated by AIR: shake damage due to the lateral and vertical motions of the ground, and fire damage due to earthquake-induced fires.

In order to calculate shake damage, the exposure information is combined with the level of shaking intensity at the building. Information on the structural characteristics of the properties at risk are used to select an appropriate damageability relationship (also sometimes called a damage function or a fragility curve) relating the probability of different levels of damage to the local shaking intensity (MMI). The damageability relationship is a complete probability distribution of damage, ranging from no damage to complete destruction (0 to 100 percent damage), with a probability corresponding to each level of damage in between. The probability distribution is a continuous function of the local MMI level.

The earthquake damageability relationships have been derived and refined over a period of several years. They incorporate well documented engineering studies by earthquake engineers and other experts both within and outside of AIR. These damageability relationships also incorporate the results of post-earthquake field surveys performed by AIR engineers and others as well as detailed analyses of actual loss data provided to AIR by its client companies. These relationships are continually refined and validated.

Fire-Following Loss Estimation

Once the shake damages have been calculated for a particular earthquake, fire-following losses are estimated. This part of the model uses a separate simulation to estimate fire losses for each event.

First, the number of fires spawned by the earthquake is generated. The fire ignition rate is based on the local MMI intensity and the total population in the area. A number of fires is simulated for each affected zip code. The mean ignition rate increases as the MMI increases. The probability distribution of ignition rates is assumed to be uniform in some interval around the mean rate. Once the number of fires is simulated, each fire is randomly placed within a zip code and is assigned to affect either residential properties, commercial properties, and/or mobile homes.

The fire simulation then simulates the spread of the fires as well as the actions taken by local fire departments to control the fires. The fire spread rate is affected by a randomly selected wind speed appropriate for the location of the earthquake. Higher wind speeds increase the rate of spread of the fire.

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Some of the factors included in the fire simulation are the time to report the fire, the time for one or more fire engines to reach the fire, and the availability of water to fight the fire. All of these factors are affected by the local MMI, as areas experiencing high shaking intensity are more likely to have obstructed roads and broken water mains. Also, the influence of fire breaks - wide roads or other natural impediments to fire spread - is included in the simulation. Fire engines can move from fire to fire as fires are controlled.

Since the fire losses are determined by simulation, different levels of fire loss can be calculated for a given earthquake. Typically, the variability of fire losses is large, at least for the larger earthquakes, such that fire losses can vary by at least a factor of two if the same earthquake is simulated several times. This reflects the true uncertainty in fire losses for larger earthquakes.

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