A BALANCED APPROACH TO EARTHQUAKE RISK USING MODERN ANALYSIS METHODS

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SUMMARY

Balanced risk methods answer fundamental questions about how organizations will fair under the loss demands of earthquake perils. Understanding earthquake risk using probabilistically derived aggregate loss distributions allows a static analysis of average annual loss for a portfolio and a conservative estimate of the probability of extreme losses to the portfolio. A random walk analysis employs dynamic models of the financial structure of the organization and exercises these models under the influence of earthquake demand through time. By analyzing the statistical outcomes of these random walks, the organization's risk management practices can be analyzed for solvency, rate of return on investment, or any other financial parameter.

INTRODUCTION

Modern risk methods offer significant advantages in determining optimal risk control structures for earthquake loss exposures. Any stakeholder that bears earthquake risk must seek the best alternative for managing loss exposures. It is recognized that these decisions are not performed in a vacuum, but instead with knowledge that the best framework for risk decisions is one that provides an understanding of relationship between random loss demand and organization's response. Ultimately, the organization seeks to avoid insolvency, but most organizations place higher expectations on their response, including quick return to normalcy, minimization of business interruption, and even, the maximization of profit during a post-earthquake epoch. Standardized earthquake risk studies, while constantly evolving, usually only report certain risk-based loss estimates. This paper advocates the full use of a simulated loss distribution for two reasons. First, it exercises the full range of potential loss scenarios on the organization. Second, it provides the ability to cascade the effect of these loss scenarios through the cash flows of an organization in order that more complete risk measures can be determined. Both motivations are in part dependent on how risk adverse the organization is and the time horizon that decisions are intended for. The statistics produced by this method yield valuable diagnostics for an organization's risk management program. These methods may be applied to organizations under diverse management objectives, where balance over the full range of outcomes is critical to the decision process.

FREQUENCY-SEVERITY RELATIONSHIPS FOR EARTHQUAKE LOSS DEMAND

The establishment of frequency-severity relationships for earthquake risk gives managers greater flexibility for controlling loss exposures according to an organization's standards. Frequency-severity relationships are usually established through multi-scenario and multi-location earthquake simulation studies, with high influence physical variables described using an appropriate risk distribution. The resulting probability density function can be reformulated as a survival function.[1] Figure 1 illustrates a representative sample of survival functions.[2]

[1] Where f(x) represents the PDF of the loss, x, then $\int f(x)\,dx = F(x)$ is the CDF, and 1-F(x) is the survival function (often called the exceedance probability function).

[2] These examples are only generic and do not represent actual distributions that may be deemed proprietary.

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Software is readily available to compute and produce a risk analysis that produces this frequency-severity relationship.

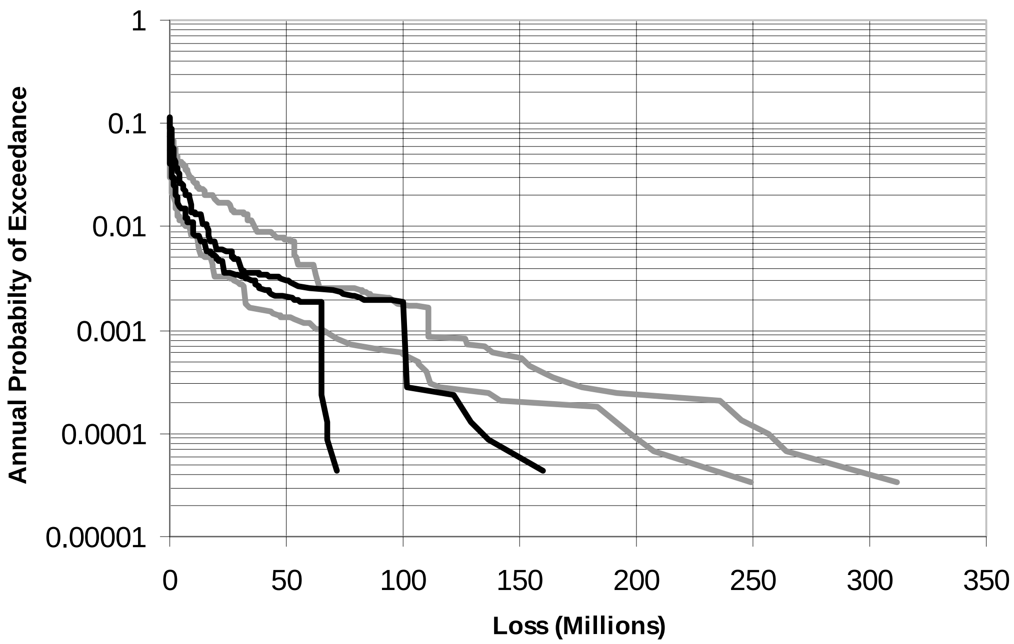

Figure 1. Example Survival Functions for Earthquake

As we move to the right tail of each survival function, loss estimates have a decreasing risk of being exceeded in any given portfolio year. The survival function is a depiction of loss severity according to loss frequency for the portfolio. The underlying information contained in the frequency-severity distribution includes correlation[3] of individual risks according to regional seismicity, local soil conditions, structural vulnerability -- all culminating in an aggregated portfolio loss estimate with a certain probability of exceedance (see Taylor et al., 1990, 1991 for details on probabilistic randomization).

Because of the mathematical complexity in dealing with statistical distributions, much of the power provided for decision-making is left behind for more simplistic measures of potential earthquake risk. Risk-based loss estimates are widely used, but tend to bias the decision-maker to the average return interval associated with that particular estimate. By definition, these measures are simply point estimates of the survival function and do not describe risk in a balanced way. We note that two distinct loss exposures can have the same loss estimate at a given average return interval, and simultaneously have very different survival functions. This "signature" property of the survival function points out the difficulty of using these types of estimates as a risk metric. Unfortunately, these measures remain the common framework for allocating "risk" in practice.

As the first moment of a very complex distribution, expected value also represents a simplistic measure of the overall distribution. For example, while the expected value of the frequency-severity distribution may be useful in comparing the relative differences between two exposures over the complete range of the distribution, the absolute risk is not revealed. Simulated loss distributions are usually positively skewed as well as leptoikutic. Still, expected loss can be useful in allocating resources or in presenting an equitable way of assigning premiums

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[3] The frequency-severity distribution implicitly describes the correlation of distinct exposure elements. Obtaining a PDF that facilitates some level of dis-aggregation is important. This enables users to better allocate and optimize risk decisions by selecting subset exposures and comparing their loss distributions to the complete portfolio.

across a region. Caution must be exercised in recognizing that any allocation method must also scale the expected loss to adequately portray the absolute risk for extreme losses, thereby recognizing the volatility of the survival distribution.

Further evidence of why these simple risk metrics are misleading is given by examining examples of these loss distributions in log-log space. Examining the ratio of the survival function to the loss severity in log-log space, as in (1) below, shows a very negative slope in the extreme tail of the survival function.[4]

$$\alpha = \frac{\log_{10}[1 - F(x)]}{\log_{10}(x)} \tag{1}$$

A survey of example distributions resulted in estimates for α less than -4. This may imply that combinations of random variables distributed according to this loss demand may indeed be quite unstable (Madelbort, 1997).

CONSTRUCTING A FINANCIAL MODEL

A financial model of the organization is a characterization of how the organization's balance sheet translates through time. In its nominal mode, the model depicts normal activity of the organization including cash flows, growth or decline in income, tax liability, and other variables. The organization's business plan normally has the information necessary to model internal and external economic variables of importance. The model should be robust enough to accommodate alternative assumptions for independent variables. This also facilitates sensitivity and influence testing.

In it's "loss absorption" mode, the model simulates the loss retention, loss control, and loss transfer mechanisms that an organization has in place. Again, of prime importance is the temporal element in organization's response to the loss, whether through its risk transfer or through the organization's own post-earthquake loss management practices. This temporal simulation captures the correlation of loss absorption with other economic risk functions. For instance, a company may find itself deploying loss reserves just as the costs for additional risk transfer are increasing since both conditions are a direct result of a severe earthquake loss.

The modelling of the macroeconomic environment also has an important effect on how the financial structure will change through time. External factors including the rate of inflation, rate of return of liquid and non-liquid investments, and market cycles affecting premium income, are necessary for a complete model of the financial structure's behaviour over time. It is also important to account for how the exposure and associated loss demand will change according to economic variables such as inflation.

For the purpose of earthquake risk assessment, the goal is to construct a financial model that dovetails with earthquake loss demands, as well as accurately depicts the baseline from which management decisions are made during nominal periods. The financial model most pertinent to organization reports parameters that are critical to the organization's mission and well being. These normally include the probability that solvency will be maintained, operations will quickly recover, profitability will prevail, and profitability will be stable (Head and Horn, 1991). The target dependent variables are sampled from the financial model before it is coupled with the earthquake loss demand model, and again, after coupling. The comparison of the final statistics allow management to gain confidence in the assumptions used in the financial model, to view how the organization is stressed using different scenarios of earthquake loss demand, and finally, to understand probabilistically the likelihood of certain financial states for a given time horizon.

THE DYNAMIC ANALYSIS

[4] The tail was defined as all losses with an average return interval of 100-years or more.

The dynamic analysis seeks to combine the earthquake demand hypothesized for a portfolio, with the organizational resources that will need to respond to these random losses. The simulation, a *random walk*, is a multi-step temporal process, whereby the present state is only a function of the state transition probabilities and the state immediately preceding it. Essentially, the objective is to understand how sums of random loss demands may coincide with other economic and financial factors to produce success or failure in the organization. As stated above, the analysis couples the financial and earthquake loss demand models.

Each random walk sample is a month-by-month simulation of the normal financial activity of the structure along with the occasional occurrence of earthquake losses. The aggregate loss distribution directly controls the earthquake loss demand subjected to the structure. For each month simulated, this distribution is queried first for the occurrence of any earthquake loss to the portfolio, and second, for which earthquake event causes the loss (if there is a loss for that month). The earthquake scenario is randomly selected (according to its relative frequency) and the characteristics of that earthquake loss are simulated on the financial structure. Such characteristics include how quickly the loss must be paid off, the effect of the loss on current reinsurance contracts, the depletion of investment income due to surplus lost, and the effect of the loss on the structure's tax status.

Results for the particular portfolio and financial structure studied are directly derived from the statistical outcome of thousands of random walks. Investment rate of return is measured by tracking asset growth, offset by expenses and loss payoffs, over each individual random walk. Expected rate of return, along with the statistical distribution for rate of return are available by examining the statistics of all random walks simulated. Similarly, asset safety can be characterized statistically by observing how frequently surpluses of the financial structure fall below some pre-assigned minimum, or when effective insolvency occurs.

APPLICATIONS AND RESULTS

This section reviews applications and results of the balanced risk approach.[5] The application examples represent two different perspectives of the earthquake risk problem -- a government public policy analysis and an insurer’s pro forma analysis. For each, we briefly illustrate the structure of the model, the form of the simulation variables, analysis problems encountered, and how results supported management’s decision process.

Government Public Policy Choices

An analysis of different insurance regulatory issues in the State of Washington focused on applying modern risk methods to quantify the financial aspects of several policy alternatives. Two major issues include consideration of a new requirement for personal lines insurance carriers to offer residential earthquake insurance and the instituting of a state-run insurance program. In particular, the private programs considered a standard single peril policy endorsement with a five-percent (5%) deductible on insured values. The public program considered would cover the lower fifteen-percent (15%) of a homeowner's earthquake loss, above a one-percent (1%) deductible on insured values.

For policy-makers to understand the financial and social consequences of instituting these regulations, it was necessary to answer several questions including:

- What premium rates are necessary to support a public insurance program?
- What are the expected earthquake losses for residential portfolios in Washington?
- What is the relationship, for both public and private insurance structures, between initial surplus, premium rate and program safety?

To address these questions, models were developed for the assumed exposure and representative insurance structures of both the private and public insurance programs. Loss distributions were developed by performing a probabilistic loss analysis on the portfolios. The financial models were then linked to the loss demand models to enable sampling of random walks over a ten-year period. Cumulative statistics were then analyzed to gauge program safety as a function of initial asset level and premium rates.

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[5] Detailed results are not presented to protect the proprietary nature of the exposures, loss demand, and subsequent results.

In this application, it was shown that the loss distribution itself could be an upper bound for the ruin probabilities. The study used proxy insurance structures and pricing to determine the solvency of the program for the initial years of existence. So, by perturbing the initial conditions of a random walk (mainly initial investment), a relationship between solvency, initial investment and premium was derived. While the original loss distribution was available for estimating solvency for a given investment level and premium rate, it is clear in this case that the associated survival function is an over estimate of the true insolvency probability (Tillman and Taylor, 1994).

Insurance Company Pro Forma Analysis

Anticipating the impact of earthquake demands is an important goal of investors, managers and employees of a new mono-line earthquake insurance company. To measure the risk and potential reward faced by various stakeholders, a model was developed to evaluate the pro forma business plan of the company. As patterned above, the model components included a description of earthquake loss demand along with a detailed model of an insurance company financial statement. These two models were then exercised to produce diagnostic statistics of various company configurations.

Earthquake demand was modelled using a proprietary risk analysis software application, operated under numerous assumptions about the growth and geographic dispersion of exposure. An important aspect of creating this earthquake demand model was building two dimensions for constraining exposure growth. First a year-by-year growth and stabilization pattern simultaneously constrained by pricing, geographic availability of exposure, company surplus growth and underwriting guidelines. Second, the exposure generation was designed to adjust its constraints according to the company and overall industry loss experience. In different epochs during the simulation, alternative loss distributions were shuttled in to characterize the correct exposure and associated loss demand.

The financial model for the insurance company was constructed to loosely follow the standardized Annual Statement. This was necessary for a number of reasons, but specifically to support an evaluation of the company using both statutory accounting and GAAP principles. Many variables were tracked on a monthly basis including:

- premiums,
- reinsurance costs,
- loss reserves and loss adjustment costs
- losses ceded to reinsurance treaties
- expenses,
- tax liabilities,
- asset earnings, and
- dividend payments to investors.

Due to the complexities of assembling such a model, we deployed the system using object oriented design paradigms. This method also facilitated the use of many alternate assumptions for important sub-components of the financial model. These sub-components included a specialized loss payout model, a model for taking the company public, and selective feedback messaging to the loss demand model.

Random walks over a five-year period were simulated using a month-by-month query on the loss demand model and propagating that result through the financial model. As the earthquake peril does not produce losses most years, the model in its nominal mode focuses on simulating the growth of the insurance company under the aforementioned constraints. The random walks were exercised thousands of times to obtain overall average, standard deviation, 90th percentile, maximum and minimum estimates for several dependent variables of interest. These include:

- effective tax rate,
- ratio of net income to equity,
- statutory surplus,
- probability of 80%, 60% and 50% depletion of cash reserves, and
- cumulative probability of depletion of cash reserves.

The overall results were applicable to helping refine the strategies taken by each stakeholder in the organization. For investors it clearly displayed the risk and uncertainly associated with their equity and potential returns. For managers, the results were used to refine the marketing approach in order that a more risk adverse stance could be achieved. From a regulatory viewpoint, the statutory controls increased the sensitivity of the company to large depletions of surplus. This in turn tended to limit the company's written premium in years following a major event and also increased the probability that state regulators would act to halt the company's operation completely.

CONCLUSIONS

A balanced approach to the earthquake risk problem calls for the integration of earthquake demand and financial models to examine the full range of potential outcomes. As established here, the characterization of frequency-severity distributions for earthquake risk falls short of providing a means for supporting decisions under risk. Using these distributions alone can lead to sub-optimal risk management choices. The balanced risk analysis approach allows for the characterisation of the complete loss demand, according to the frequency-severity relationship already established, but also coupled with a financial model of the organisation's operation. This is accomplished using random walk simulations that result in statistical statements of the organization's ability to absorb earthquake loss. In this way better risk metrics are established based on information pertinent to the decision-maker.

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