Fair Insurance Guaranty Premia in the Presence of Risk-Based Capital Regulations, Stochastic Interest Rate and Catastrophe Risk

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Abstract

A multiperiod model is developed to measure the costs posed to the guaranty fund in a setting that incorporates risk-based capital regulations, interest rate risk and the possibility of catastrophic losses. The guaranty contract is modeled as a put option on the asset of the insurance company with a stochastic strike price and an uncertain maturity. The impacts of the key factors of this model are examined numerically and shown to make material differences in the costs to the guaranty fund.

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1 Introduction

In the U.S., the primary regulatory responsibility over insurance companies rests with the authorities in the domiciled state. There are 55 jurisdictions (50 states, four territories and the District of Columbia). There is no centralized federal authority to oversee regulations of insurance companies. That being said, the body of state laws and regulations do exhibit a high degree of similarity due to coordination among the state regulators and development of uniform policies through the National Association of Insurance Commissioners (NAIC), an organization created in 1871. In practice, model laws and regulations are first developed by the NAIC. The member jurisdictions then adopt substantially equivalent versions of these model laws and regulations, which is the condition for obtaining a formal NAIC accreditation.

In order to maintain an orderly insurance market, insurance guaranty funds are set up state-by-state to deal with the policy obligations left by insolvent insurers.[1] Most jurisdictions adopt a post-assessment approach, meaning that the policy obligations of a failed insurer will be distributed, *pro rata* based on the premium volume up to a statutory ceiling (typically set at 2%), among other insurance companies in the same jurisdiction. Separate insurance guaranty funds are set up for different categories of risks insured such as life/health insurers, property/casualty insurers, among others.[2]

The current regulatory practice is best characterized as a risk-based capital (RBC) approach, adopted by the NAIC in 1994, to determining the suitable regulatory actions in response to potential insolvency risk. The RBC for an insurer is determined by a formula which takes into account asset risk, underwriting risk, interest rate risk and other risks (such as the credit risk charge for reinsurance recoverable). The formula value then leads to five action levels: no action, company action level, regulatory action level, authorized control level and mandatory control level. These action levels are determined in relation to a formula value known as the Authorized Control Level RBC. When an insurer's total adjusted capital (approximately equals total surplus for most insurers) falls below the authorized control level, an insurer may be placed under regulatory control but the state insurance commissioner is accorded with some discretion. If the total adjusted capital falls below the mandatory control level (70% of the authorized control level), then the insurer must be placed under regulatory control.[3] The statutory requirement for the state insurance commissioner to intervene based on the explicit RBC calculations means that forbearance is

[1] Han, *et. al.* (1997) discuss the pros and cons of the current state-by-state guaranty funds versus the proposed interstate systems in terms of the well-being of policyholders, shareholders and taxpayers.

[2] New York is the only jurisdiction that adopts the pre-assessment approach to all lines of insurance guaranty. Other states choose to employ the pre-assessment approach to some lines of insurance; for example, the workers compensation insurance in New Jersey and Pennsylvania.

[3] The company action level and regulatory action levels are defined at 200% and 150% of the authorized control level, respectively. See the document "General Overview of Risk-Based Capital" at http://www.naic.org/frs/rbc/index.htm.

no longer permitted under the current regulatory regime in the U.S.[4]

This paper develops a multiperiod model to determine risk-based "fair" premia for insurance guaranty funds. The fair premium serves as an important conceptual device for understanding the financial costs to the guaranty fund, even though the current practice fundamentally differs from a risk-based pre-assessment approach.[5] Different fair premium rates for different insurers, for example, will suggest that the RBC standards have been ineffective from a valuation perspective in factoring in the differences across insurers. This thus provides an informative way of examining the RBC standards from a perspective different from that of Grace, *et. al.* (1998) who were mainly concerned with the ability of the RBC/surplus ratio in predicting insolvencies. Arguably, the RBC standards are meant as a regulatory control device rather than a mechanism to predict future insolvencies or to level the costs posed by different insurers to the guaranty fund. Nevertheless, a system relying on cross subsidization among insurers on a post-assessment basis is neither a just nor efficient way of running an insurance market. Toward this end, we contend that the "fair" premium on a pre-assessment basis can be adopted to complement the RBC standards to achieve the objective of a stable and yet fair insurance market.

Our approach extends Cummins' (1988) one-period model into a multiperiod setting in which we also incorporate interest rate uncertainty and the regulatory responses mandated by RBC regulations. In our model, all insolvent insurers are resolved immediately during the period when an insolvency occurs. For an insurer that remains solvent but falls below the mandatory control level, the state insurance regulator is required to take over the control of the insurer. We assume that the state insurance regulator takes actions to reduce the underwriting intensity and/or to lower the asset portfolio risk. The regulatory response thus fundamentally alters the nature of an insurer and generates some interesting dynamic implications. Although our model explicitly excludes forbearance in order to reflect the current state of the regulatory practices in the U.S., forbearance can still be expected in other jurisdictions where regulators are less vigilant.[6] Our model can be readily modified to accommodate forbearance if needed.

Our model follows Merton (1977) and a long line of literature that models guaranty as a put option. Merton (1978) and Pennacchi (1987a) consider deposit insurance pricing with a

[4]When facing a financially distressed insurer, the state regulator was naturally reluctant to take actions against the insurer for fearing the economic fallouts from the regulatory actions. According to a GAO (1991) report, during the period of 1980-1989, state regulators did not take their first formal action against 71 percent of failed insurer cases until after the insurers became insolvent. Over a third of the insolvencies, in fact, were not resolved after another year. The RBC standards were in effect a response to the practice of forbearance among state insurance regulators. Cummins, *et. al.* (1995), however, provided evidence that improvements in the RBC formula are needed in order to facilitate prompt corrective actions so as to reduce insolvency costs.

[5]A fair pre-assessment value is effectively the economic value of such a contingent claim to which two counter-parties operating in an competitive market would agree.

[6]Kane (2001) explains why capital forbearance is pervasive in the regulated financial industry.

stochastic audit. Ronn and Verma (1986) incorporate capital forbearance, while McCulloch (1985), Pennacchi (1987b), and Duan, *et. al.* (1995) consider stochastic interest rates. Duan and Yu (1994, 1999) and Cooperstein, *et. al.* (1995) consider deposit insurance in light of regulatory responses and capital adjustments in the multiperiod setting. Cummins (1988) extends the option pricing approach to property-liability insurers by incorporating stochastic liability.[7] Our model is, at the conceptual level, more in line with the approach of Duan and Yu (1994, 1999), who model deposit insurance in a multiperiod framework by allowing contingent responses by the bank and the regulator. We have, however, adapted it to reflect the regulatory reality of the insurance market in the U.S.

The guaranty contract extended to the insurer in our model is of multiple years in duration. Since an insurer may become insolvent at an annual audit, the *de facto* maturity of the guaranty contract is stochastic and not known *ex ante*. The potential regulatory intervention is also expected to increase the *de facto* maturity. From this perspective, the risk-based premium in our model can be viewed as a put option with a stochastic strike price and an uncertain maturity. Our incorporation of the RBC standards and the corresponding regulatory actions into the model amounts to an explicit recognition of the trilateral bonding nature of an insurance guaranty fund, a point well articulated by Kane (1995) in the context of deposit insurance.

Our guaranty valuation problem is further complicated by a number of practical considerations. Insurers largely hold financial assets that are interest rate sensitive. This fact makes the consideration of interest rate risk particularly important. On the other hand, the liabilities facing these insurers are non-financial and closely related to external events such as hurricanes, earthquakes, terrorist attacks, and so on. This fact prompts us to adopt a jump-diffusion model to describe their liability dynamics.

Our model and numerical analysis show that coverage horizon has a significant impact on the fair premium rate. The leverage position of an insurer is critical in determining whether the fair premium rate increases or decreases with coverage horizon. Not surprisingly, either the intensity of catastrophe occurrence or the risk management practice of an insurer will affect the guaranty cost. Finally, the regulatory action has an effect of lowering the guaranty cost, and its effect depends on the vigilance level of the insurance regulator.

[7] Related work in insurance pricing includes Kraus and Ross (1982) and Doherty and Garven (1986). The former uses arbitrage pricing theory to develop equilibrium premia for property-liability insurers, while the latter presents a contingent-claim model of the property-liability firm.

2 A model for the insurer's balance sheet

2.1 The asset value dynamic

In the literature the asset value dynamic is typically modeled by a lognormal diffusion process; for example, Merton (1977) and Cummins (1988). This modeling approach fails to explicitly take into account the impact of stochastic interest rates on the asset's value. This shortcoming is particularly important for modeling an insurance company's assets, because it is common for insurers to hold a large proportion of fixed-income assets in their portfolios. We thus adopt the approach of Duan, *et. al.* (1995) to describe the insurer's total asset value as consisting of two risk components – interest rate and asset risks. We use asset risk here as opposed to credit risk by Duan, *et. al.* (1995) to better reflect the fact that it is a term capturing all asset risks that are orthogonal to the interest rate risk.

Specifically, the value dynamic for the insurer's assets is governed by the following process:

$$dA_t = \left[(r_t + \mu_A) A_t + (\eta - \kappa) L_{t\_} \right] dt + \phi_A A_t dr_t + \sigma_A A_t dW_{A,t}, \tag{1}$$

where A_t is the value of the insurer's assets at time t; L_t is the insurer's total contractual liabilities at time t modeled as the time-t value of all future claims related to the outstanding policies by assuming that all of its contractual obligations are honored; r_t is the instantaneous interest rate at time t; $W_{A,t}$ is a Weiner process denoting the asset risk; σ_A is the volatility parameter for the asset risk; ϕ_A is the instantaneous interest rate elasticity of the insurer's assets; μ_A is the risk premium associated with the asset risk; η is the underwriting intensity parameter capturing the net rate of increase in the underwriting activities; and κ is the rate of claim payments net of policy premium proceeds. If $\kappa = 0$, the insurer is in a break-even state that the premia inflow and claims outflow are balanced out on average. Note that $L_{t\_}$ denotes the left limit of the liability process at time t, which is used to accommodate jumps in liabilities to be described later.

Duan, *et. al.* (1995) use the Ornstein-Uhlenbeck process to describe interest rates. They hence can take advantage of the Vasicek (1977) bond pricing formula. Here we choose to use the square-root process of Cox, *et. al.* (1985) to describe the interest rate dynamic. There are two reasons for doing so. First, the square-root process can ensure non-negative interest rates. Second, our incorporation of regulatory responses already prevents us from deriving any closed-form formula even if we use the same set-up as in Duan, *et. al.* (1995).

The instantaneous interest rate is assumed to follow:

$$dr_t = \alpha(m - r_t)dt + v\sqrt{r_t}dZ_t, \tag{2}$$

where m is the long-run mean of the interest rate; v is the volatility parameter for the interest rate; α is a positive constant measuring the mean reverting intensity; and Z_t is a Wiener process independent of $W_{A,t}$. Combining (1) and (2) yields

$$dA_t = \left[(r_t + \mu_A + \phi_A \alpha m - \phi_A \alpha r_t) A_t + (\eta - \kappa) L_{t\_} \right] dt + \phi_A v \sqrt{r_t} A_t dZ_t + \sigma_A A_t dW_{A,t}. \tag{3}$$

It is clear that under our assumption, A_t is not a lognormal process.

For derivative pricing, it is a standard practice to use the device of risk-neutralization. The interest rate dynamic under the risk-neutral pricing measure, denoted by Q, can be written as

$$dr_t = \alpha^*(m^* - r_t)dt + v\sqrt{r_t}dZ_t^*, \tag{4}$$

where α^*, m^* and Z_t^* are defined as

$$\begin{aligned} \alpha^* &= \alpha + \lambda \\ m^* &= \frac{\alpha m}{\alpha + \lambda} \\ dZ_t^* &= dZ_t + \frac{\lambda\sqrt{r_t}}{v}dt. \end{aligned}$$

Term λ is interpreted as the market price of interest rate risk and is a constant under the Cox, *et. al.* (1985) assumption, while Z_t^* is a Wiener process under Q.

The insurer's asset value dynamic can thus be risk-neutralized to become

$$dA_t = \left[r_t A_t + (\eta - \kappa) L_{t_-}\right] dt + \phi_A v\sqrt{r_t}A_t dZ_t^* + \sigma_A A_t dW_{A,t}^*, \tag{5}$$

where $W_{A,t}^*$ is a Wiener process under Q and it continues to be independent of Z_t^* by invoking the standard martingale pricing theory. The above expression simply states that the insurer's assets (excluding the addition from the net of the new underwriting activities and claims payments) are expected to earn a risk-free rate of interest in a risk-neutral world.

Equations (4) and (5) together do not completely characterize the pricing system because the insurer's liabilities are driven by other stochastic factors.

2.2 Catastrophe and the liability dynamic

Recall that an insurer's total contractual liabilities L_t is the time-t value of all future claims related to the outstanding policies, assuming that all of its contractual obligations are honored. With the possibility of default, the market value at time t of its liabilities must be less than L_t. The cost to the guaranty fund precisely reflects the event in which the insurer's asset value is less than L_t.

The change in the total contractual liabilities is assumed to be stochastic and consists of two components. The first component reflects the fact that the insurer is subject to large jumps in liabilities, i.e., catastrophes. In property insurance, for example, a major hurricane or terrorist attack could cause widespread damages to an area such that an insurer could face a staggering amount of claims. We use a compound Poisson process to model this change in liabilities. Cummins (1988) and Shimko (1992) make the same assumption regarding the jump risk in their valuation of insurance liabilities.

The second component of the change represents normal variations in liabilities and is modeled as a continuous diffusion process. Since L_t is the present value of all future claims (assuming that the contractual liabilities are honored), the continuous component should reflect the effects of interest rate changes and other day-to-day small shocks. These considerations together lead us to specify an overall process for L_t as follows:

$$\begin{aligned} dL_t &= \left(r_t + \eta + \mu_L - \phi_L \alpha m + \phi_L \alpha r_t - \theta e^{\mu_y + \frac{1}{2}\sigma_y^2}\right) L_{t\_} dt \\ &\quad + \phi_L L_{t\_} dr_t + \sigma_L L_{t\_} dW_{L,t} + Y_{P_{L,t}} L_{t\_} dP_{L,t}, \end{aligned} \tag{6}$$

where Y_j is a sequence of independent and identically-distributed positive random variables describing the percentage change in liabilities in the event of a jump; and $P_{L,t}$ is a Poisson process with intensity parameter θ independent of all other random variables. Since L_t is the present value of liabilities assuming that the contractual obligations will be honored, it will thus grow at the rate of r_t if there are no new underwriting activities or external shocks. Parameter μ_L denotes the risk premium for all shocks, and recall that η is the net rate of increase in the underwriting activities. The remaining terms in the coefficient of dt are used to offset the drift rate in interest rates and the anticipated increase in liabilities due to catastrophes.

Due to jumps, the liability process has sample paths that are right continuous. We assume that $\ln(Y_j)$ has a normal distribution with mean μ_y and standard deviation σ_y. This assumption ensures that a catastrophe always causes liabilities to rise even though the magnitude is random. $W_{L,t}$ summarizes all continuous shocks that are not related to the interest rate or asset risk of an insurer; that is, it is assumed to be independent of r_t and $W_{A,t}$. The other parameters in equation (6) have similar interpretations as those in equation (1). Using equation (2), we can rewrite the contractual liability dynamic as

$$dL_t = \left(r_t + \eta + \mu_L - \theta e^{\mu_y + \frac{1}{2}\sigma_y^2}\right) L_{t\_} dt + \phi_L v \sqrt{r_t} L_{t\_} dZ_t + \sigma_L L_{t\_} dW_{L,t} + Y_{P_{L,t}} L_{t\_} dP_{L,t}. \tag{7}$$

Note that the term $-\theta e^{\mu_y + \frac{1}{2}\sigma_y^2}$ offsets the drift arising from the compound Poisson component $Y_{P_{L,t}} L_{t\_} dP_{L,t}$ so that $r_t + \eta + \mu_L$ becomes the real drift of the system. Although one can absorb the compound Poisson drift into μ_L, it will complicate the interpretation of the model.

For valuation purposes, we need to know the liability dynamic under the risk-neutral pricing measure Q. We follow Merton (1976) and Cummins (1988) to assume that catastrophe risk may be hedgeable through reinsurance and derivative securities. Since $W_{L,t}$, Y_j, and $P_{L,t}$ pertain to idiosyncratic shocks to the liabilities, we will assume a zero risk premium for these three risks.[8] The interest rate shock, on the other hand, can be risk-neutralized using

[8] Catastrophe risk may not be hedgeable if it has a wide-ranging implications beyond the insurance sector. The 9/11 terrorist attacks can be viewed as such a catastrophe. One may want to attach risk premia to all three stochastic variables pertinent to catastrophe. Alternatively, one can classify catastrophes into two categories - market-wide and firm-specific - and only allow for the market-wide catastrophe to be assigned non-zero risk premia.

the result in equation (4) so as to substitute out Z_t with Z_t^*.

As a result, we have the following dynamic under the risk-neutral pricing measure, Q:

$$dL_t = \left(r_t + \eta - \theta e^{\mu_y + \frac{1}{2}\sigma_y^2}\right) L_{t\_} dt + \phi_L v \sqrt{r_t} L_{t\_} dZ_t^* + \sigma_L L_{t\_} dW_{L,t}^* + Y_{P_{L,t}^*} L_{t\_} dP_{L,t}^*, \qquad (8)$$

where $W_{L,t}^*$, Y_j^*, and $P_{L,t}^*$ retain (due to the zero risk premium assumption) their original distributional characteristics after changing from the physical probability measure to the risk-neutral pricing measure. The presence of the term $\theta e^{\mu_y + \frac{1}{2}\sigma_y^2}$ in equation (8) reflects the fact that $E_t^Q\left(Y_{P_{L,t}^*}^* dP_{L,t}^*\right) = \theta e^{\mu_y + \frac{1}{2}\sigma_y^2} dt$. In other words, with this term compensating for the expected growth in $Y_{P_{L,t}^*}^* dP_{L,t}^*$, we can be certain that L_t (excluding the addition from the new underwriting activities, i.e., η) indeed grows at the risk-free rate in the risk-neutral world.

3 Risk-based premium for the insurance guaranty fund

The risk-based premium can be viewed as a put option on the assets of the insurer. In our set-up, however, the valuation problem is complicated by the fact that the exercise price is stochastic and subject to jumps. The intrinsic cost of such a guaranty contract also critically depends on regulatory responses required by laws. The effects of the regulatory factor can only be analyzed in a multiperiod setting which explicitly allows for regulatory responses contingent upon the capital position of the insurer at the time of audit.

In the U.S., insurers are required to file regulatory reports on a quarterly basis. They are also subjected to detailed off-site audits annually and more thorough on-site examinations every three to five years. Insurers are deemed insolvent and face liquidation if the value of their assets falls below that of their liabilities at the time of audit. For the modeling purpose, we set the periodic audit times generically as $t = 0, 1, 2, \cdots$. As a result, the guaranty contract is a put option with a random closure time,[9] $\tau \equiv \min\{i \in \{0, 1, 2, \cdots\}$ such that $A_i < L_i\}$.

As discussed in the introduction, the current regulatory framework in the US requires mandatory control by the state insurance commissioner whenever the total adjusted capital of an insurer falls below 70% of the authorized control level RBC even if the insurer remains solvent. Mandatory control means that the insurance commissioner or his/her appointee will effectively run the insurance company. Presumably, the steps will be taken to change management practices, alter the asset mix and modify underwriting activities. The appointee

[9] If forbearance is practised, the condition in defining the closure time can be changed to $A_t < cL_t$, where c is some value less than 1. It should be noted, however, that a constant forbearance parameter cannot fully reflect the optional nature of forbearance. Obviously, forbearance is mainly influenced by the economic and political forces of the time.

is in effect a short-horizon fund manager who is mainly interested in adopting a “stop-loss risk-reduction” strategy to safeguard the interests of the policyholders and the guaranty fund. In contrast, the original management is more likely to implement “double-up” or “let-it-ride” strategies to benefit shareholders for the matters concerning the asset portfolio and the underwriting activities.

The RBC formula consists of a complex set of rules to reflect various aspects of the risks facing insurers. In essence, the formula imposes a capital standard tighter than the solvency test so as to reduce the probability of default by the insurer. For modeling purposes, we make the simplifying assumption that the RBC formula can be summarized into an insurer-specific regulatory vigilance parameter $\rho > 1$ and mandatory control will take place when $A_i < \rho L_i$.

It should be noted that regulatory actions are only relevant when the insurer remains solvent, i.e., when $\tau > i$, and it is possible for an insurer in rehabilitation to further deteriorate into insolvency. As well, an insurer in rehabilitation is allowed to go back to its original *modus operandi* once it meets the RBC standards. Specifically, we consider three regulatory actions and provide concrete modeling specifications for them.

1. Reducing asset risk: let $0 < c_A \leq \sigma_A$,

$$\sigma_A(i) = \begin{cases} \sigma_A & \text{if } A_i \geq \rho L_i \\ \sigma_A - c_A & \text{otherwise} \end{cases} \tag{9}$$

2. Reducing underwriting intensity: let $c_U \leq \eta$,

$$\eta(i) = \begin{cases} \eta & \text{if } A_i \geq \rho L_i \\ \eta - c_U & \text{otherwise} \end{cases} \tag{10}$$

   We do not set a lower bound for the underwriting intensity to allow for cases where the insurer winds down its underwriting activities.

3. Reducing both asset risk and underwriting intensity: both (1) and (2) take place concurrently.

Since the equity holders of a profitable insurer are likely to withdraw excess capital, we place a ceiling on the insurer's asset value to reflect this behavior. As a result, the asset value is subject to reset periodically. Specifically, the asset value adjustment mechanism at auditing times is modeled as

$$A_i = \begin{cases} q_u L_i & \text{if } A_i \geq q_u L_i \\ A_i & \text{otherwise} \end{cases} \tag{11}$$

where $q_u > \rho$ sets the upper bound on the capital position.

Let n be a pre-set terminal time of guaranty fund coverage. Denote $\tau \wedge n$ as the minimum of τ and n. The liability facing the guaranty fund at any auditing time $t = 0, 1, 2, \cdots$, denoted by $C(i), i = 0, 1, 2, \cdots$, can be described by

$$C(i) = \begin{cases} \max(L_i - A_i, 0) & \text{if} \quad i = \tau \wedge n \\ 0 & \text{if} \quad i \neq \tau \wedge n. \end{cases} \tag{12}$$

The liability can occur only once with an amount equal to $\max(L_i - A_i, 0)$. A strictly positive liability can occur even with $\rho > 1$ because (1) audits are conducted periodically and (2) liabilities are subject to jumps.

Let δ_n denote the fair premium rate per period over an intended n-period (auditing period) of guaranty coverage. The fair premium rate can be viewed as a risk-adjusted quantity that equates the present value of $\tau \wedge n$-period insurance levies with the present value of the total guaranty coverage. This fair premium rate is, of course, only a conceptual device, but it serves as a convenient way of measuring the guaranty coverage value in a standardized fashion. Specifically, the fair premium rate is the solution to the following system:

$$E_0^Q \left(\sum_{i=0}^{\tau \wedge n-1} e^{-\int_0^i r_s ds} \delta_n L_i \right) = E_0^Q \left(e^{-\int_0^{\tau \wedge n} r_s ds} C(\tau \wedge n) \right) \tag{13}$$

where $E_0^Q(\cdot)$ denotes expectation taken at time 0 with respect to the dynamics specified in (4), (5) and (8).

The right-hand side of equation (13) is the present value of the liability facing the guaranty fund. The left-hand side is the present value of insurance premium payments. This expression is consistent with the fact that the insurance premium payment is stopped when the insurer is found, upon audit, to be insolvent, and the fact that the premium payments are made at the beginning of every period when coverage is in effect. In other words, the premium payments are made on a pre-assessment basis.

4 Numerical analysis

4.1 Simulation method

In this section we numerically assess the fair premium rate using the guaranty pricing model discussed in the earlier sections. From equation (13), the fair premium rate can be written as

$$\delta_n = \frac{E_0^Q \left(e^{-\int_0^{\tau \wedge n} r_s ds} C(\tau \wedge n) \right)}{E_0^Q \left(\sum_{i=0}^{\tau \wedge n-1} e^{-\int_0^i r_s ds} L_i \right)}. \tag{14}$$

Both the denominator and numerator of the above expression can be computed by Monte Carlo simulations. However, this numerical pricing problem may be simplified by partially solving the two stochastic differential equations specified in (5) and (8).

Applying Ito's lemma to the logarithm of the asset value, equation (5) becomes:

$$d\ln(A_t) = \left(r_t + (\eta - \kappa)\frac{L_{t_-}}{A_t} - \frac{1}{2}\phi_A^2 v^2 r_t - \frac{1}{2}\sigma_A^2\right)dt + \phi_A v\sqrt{r_t}dZ_t^* + \sigma_A dW_{A,t}^*. \qquad (15)$$

Factoring in the regulatory responses described in the preceding section, we can solve the above equation between the i-th and the $(i+1)$-th auditing times. For any $0 \leq q < 1$, the solution is

$$\begin{aligned} A_{i+q} &= A_i \exp\left(\sigma_A(W_{A,i+q}^* - W_{A,i}^*) - \frac{1}{2}\sigma_A^2(i)q\right) \\ &\quad \times \exp\left[(\eta(i) - \kappa)\int_i^{i+q}\frac{L_{s_-}}{A_s}ds + \left(1 - \frac{1}{2}\phi_A^2 v^2\right)\int_i^{i+q} r_s ds + \phi_A v\int_i^{i+q}\sqrt{r_s}dZ_s^*\right] \end{aligned} \qquad (16)$$

Similarly, by Ito's lemma, equation (8) gives rise to

$$d\ln L_t = \left[r_t + \eta - \theta e^{\mu_y + \frac{1}{2}\sigma_y^2} - \frac{1}{2}\phi_L^2 v^2 r_t - \frac{1}{2}\sigma_L^2\right]dt + \phi_L v\sqrt{r_t}dZ_t^* + \sigma_L dW_{L,t}^* + \ln(1 + Y_{P_{L,t}^*}^*)dP_{L,t}^* \qquad (17)$$

and its solution is

$$\begin{aligned} L_{i+q} &= L_i \exp\left[\sigma_L(W_{L,i+q}^* - W_{L,i}^*) + \left(\eta(i) - \theta e^{\mu_y + \frac{1}{2}\sigma_y^2} - \frac{1}{2}\sigma_L^2\right)q + \sum_{j=P_{L,i}^*}^{P_{L,i+q}^*}\ln(1 + Y_j^*)\right] \\ &\quad \times \exp\left[\left(1 - \frac{1}{2}\phi_L^2 v^2\right)\int_i^{i+q} r_s ds + \phi_L v\int_i^{i+q}\sqrt{r_s}dZ_s^*\right]. \end{aligned} \qquad (18)$$

These solutions suggest a simple way of simulating asset and liability values at the auditing time points. If $\eta(i) = \kappa$, we can simulate the risk-neutral interest rate process as in equation (4) on, say, a daily basis to approximate the whole sample path from one auditing time to the next. This in turn allows us to compute two quantities of interest: $\int_i^{i+1} r_s ds$ and $\int_i^{i+1}\sqrt{r_s}dZ_s^*$. Second, we simulate $(W_{A,i+1}^* - W_{A,i}^*)$ using the fact that it is independent of the path of r_t. Combining $(W_{A,i+1}^* - W_{A,i}^*)$ with the simulated $\int_i^{i+1} r_s ds$ and $\int_i^{i+1}\sqrt{r_s}dZ_s^*$ yields a simulated value for A_{i+1} as described in equation (16). Third, we generate $(W_{L,i+1}^* - W_{L,i}^*)$ using a similar procedure. Fourth, $(P_{L,i+1}^* - P_{L,i}^*)$ can be generated by recognizing that it has a Poisson distribution with intensity parameter θ. Finally, for a given value of $(P_{L,i+1}^* - P_{L,i}^*)$, we simulate $\sum_{j=P_{L,i}^*}^{P_{L,i+1}^*}\ln(1 + Y_j^*)$, knowing that $\ln(Y_j^*)$ are *i.i.d.* normal random variables with a common mean μ_y and variance σ_y^2 for all j's, conditional on $(P^*_{L,i+1} - P^*_{L,i})$. Using these simulated variables in conjunction with the values generated for $\int_i^{i+1} r_s ds$ and $\int_i^{i+1} \sqrt{r_s} dZ^*_s$, we obtain L_{i+1} as described in equation (18).

If $\eta(i) \neq \kappa$, simulation must be carried out simultaneously for all three stochastic processes. Specifically, the term $\int_i^{i+q} \frac{L_{s-}}{A_s} ds$ in equation (16) links the asset value process to the liability dynamic. Due to the regulatory response described in equation (10), this inevitably becomes the relevant simulation situation. In actual implementation, we adopt one year as the length of the auditing period and approximate the three-equation stochastic system by discretizing it on a daily basis; that is, we set $q = k/365$ with $k = 1, 2, \cdots, 365$.

After simulating these three processes, the guarantee value as well as the total present value of all premium payments can be calculated via averaging over the contingent payoffs corresponding to the simulated values. In short, we have devised an efficient way of computing the fair premium rate, δ_n.

4.2 Parameter values

As a reference point for the numerical analysis, a base set of parameters is established and summarized in Table 1. Deviations from the base values provide insight into how changes in the characteristics of the asset-liability structure, interest rate process, catastrophe risk and regulatory policy affect the guaranty values. The basic unit of coverage horizon is assumed to be one year, and auditing takes place at the end of the year. We consider the initial capital positions or the asset-liability (A/L) ratios of 1.1, 1.3, and 1.5, respectively.[10]

The difference in the interest rate elasticity of the insurer's assets and liabilities measures the degree of mismatch in the interest rate risk exposure of assets and liabilities. Thus, the term $(\phi_A - \phi_L)$ is referred to as the interest rate elasticity gap. We set the interest rate elasticity pair to $(-7, -3)$, $(-3 * \frac{L}{A}, -3)$, and $(0, 0)$, respectively, to measure different scenarios of interest rate elasticity gaps.[11] The asset risk is set at 5%. The parameters for the Cox, *et. al.* (1985) model are the estimates reported in Table 2A of Duan and Simonato (1999) with the initial interest rate set equal to the long-run average.

The parameter governing new underwriting activities in the asset and liability dynamics, i.e., η, is set equal to 8%. We also assume that the insurer is in the break-even state, i.e., $\kappa = 0$; that is, the insurer has attained a steady-state position where premia inflow and claims outflow are equal on average. Catastrophe strikes according to a Poisson process with an intensity θ so that the probability of a catastrophe in a small interval of time is θdt. The value of θ is set to either 0.33 or 0.1 so as to represent, on average, one catastrophe event

[10] Cummins (1988) bases on data of 1980s to use the ratios from 1.2 to 1.4 in his simulation analysis. A.M. Best's Aggregates and Averages reports the industry's A/L ratio of 1.55 in 1997 and 1.58 in 1998.

[11] The value-weighted effective durations of assets and liabilities range from 3 to 7 years, see Santomero and Babbel (1997).

every three or ten years, respectively. The occurrence of a jump causes the liability to grow in value at a percentage equal to Y, where $\ln Y$ is assumed to be normally distributed with $\mu_Y = -2.3075851$ and $\sigma_Y = 0.1$. These two parameter values together imply an average of a 10% jump magnitude when a jump occurs, because $\exp(\mu_y + \frac{1}{2}\sigma_y^2) = 0.1$.[12] In addition, the volatility for the pure liability diffusion process (σ_L) is set at 3%.[13] The asset value will be reset periodically at the auditing times to remove excess capital. The threshold asset level for disbursing cash dividends, q_u, is assumed to be 1.5.

The coverage horizons considered range from 1 to 10 years. Arguably the coverage horizon is infinity because as long as an insurer stays solvent insurance guaranty continues. By such an interpretation, our analysis up to 10 years provides an indication about the asymptotic behavior. Alternatively, one may view the coverage horizon as the perceived regulatory and/or pricing cycle in the sense that the regulatory environment is expected to change and/or a new guaranty premium rate is expected to take effect.

Table 2 presents the case with the regulatory response being the first type; that is, the insurer in rehabilitation is forced to decrease its asset risk. Specifically, we assume that asset risk is decreased from 5% to 0%. Table 3 provides the results corresponding to the second type of regulatory response, which lowers its underwriting intensity from 8% to 0%. The results corresponding to the third type of regulatory response, i.e., the first and second combined, are given in Table 4. For comparison purposes, we also provide in this table the results under no regulatory responses. In addition, we adopt the estimate for interest rate risk premium reported in Duan and Simonato (1999) and set the risk premium λ to -0.111. The estimate is negative mainly due to the definition of risk premium adopted in Cox, *et. al.* (1985). This value is used in Tables 2-4 but is later set to 0 in Table 5 to examine its effects. In each table, we categorize fair premium rates according to three scenarios of leverage, three interest rate sensitivity structures and two levels of catastrophe intensity.

4.3 Guaranty value

All fair guaranty premium rates are computed with Monte Carlo simulation of $50,000$ sample paths. The premium rates for various coverage horizons are reported in Tables 2-5. These tables show the basic pattern as to how premium rates are related to the initial capital position, the interest rate elasticity gap, the catastrophe intensity and the coverage horizon. It should be noted that the fair premium rate is determined on a pre-assessment basis. Such

[12] Two major catastrophes - Hurricane Andrew and the 9/11 World Trade Center terrorist attacks - occurred in the U.S. in 1992 and 2001, respectively. Arguably our catastrophe intensity parameters of 0.33 and 0.1, implying respectively one catastrophe every three and ten years, seem to be on the high side. The use of these specific parameter values should be understood as for the illustrative purpose.

[13] The volatility of industry liabilities ($\sqrt{\phi_L^2 v^2 r_t + \sigma_L^2 + \theta \, \sigma_y^2}$) was about 0.067 over the last 25 years and the assumption of the pure liability volatility (σ_L) to be 0.03 matches with the values of jump intensity (θ =0.1), interest rate elasticity of liabilities ($\phi_L = -3$) and other base-set values of parameters.

a rate is *ex ante* and insurer-specific as opposed to the post-assessment industry average that is *ex post* and does not reflect the nature of a given insurer.

4.3.1 Coverage horizon

We observe from Table 2 that the annualized fair premium rate increases with the coverage horizon for the low-leverage insurer ($A/L = 1.5$ or 1.3), but decreases for the high-leverage firm ($A/L = 1.1$). In the case of the former, the result is intuitive because a low-leverage insurer presents a lower guaranty cost for earlier periods and the initial leverage-effect is lessened over time when the coverage horizon is extended. Under our assumption, the insurer will begin to pay dividends so as to cap the asset-liability ratio at 1.5. This ceiling forces a lower asset-liability ratio in the future and thus raises the guaranty cost for distant periods. For the high-leverage insurer, the situation is reversed because it is more likely to default in the earlier periods and the initial leverage-effect then dissipates over time.

Adding to the effect on the fair premium rate is the interplay between the coverage horizon and the regulatory responses. In the event that an insurer falls under mandatory control, the regulatory authority takes actions to lower the insurer's asset risk (Table 2), to lower its underwriting intensity (Table 3), or to do both (Table 4). Not surprisingly, these actions have the effect of lowering the fair premium rate for all coverage horizons. A high-leverage insurer, as compared to a low-leverage one, is more likely to face the regulatory actions in the short run and such actions fundamentally change the nature of the insurer and thus the fair premium rate.

4.3.2 Leverage and catastrophe risks

Since either a high initial leverage or a high catastrophe intensity implies a higher insolvency risk, we expect to see a higher fair premium rate. As a result, the premium rates in the bottom panel of either Table 2 or 3 are the highest as compared to the other two leverage scenarios. Similarly, the fair premium rate increases when the level of catastrophe intensity is increased from 0.1 (one in ten years) to 0.33 (one in three years) in Tables 2-5. We also observe that the fair premium rate for a low-leverage insurer changes more substantially (in a relative sense) across the coverage horizon as compared to that for a high-leverage insurer. For example, the one- and two-period premium rates under $A/L = 1.5$ are 0.088 and 2.556 basis points, respectively (column 1, top panel, Table 2). This increase is more substantial in terms of percentage as compared to the corresponding rates under $A/L = 1.3$, which are 4.212 and 17.215 basis points, respectively (column 1, middle panel, Table 2). The same conclusion holds for different interest rate elasticity structures.

4.3.3 Interest rate risk and risk premium

We consider three interest rate elasticity scenarios: $(\phi_A, \phi_L) = (-7, -3), (-3 \times \frac{L}{A}, -3)$, and $(0, 0)$. The second scenario has a zero size-adjusted interest rate elasticity gap, which can be regarded as an active interest risk management practice that strives to eliminate the interest rate risk facing the insurer by adjusting the asset-liability mix. The third case, on the other hand, is for an insurer whose assets and liabilities are interest rate insensitive.

We observe that the fair premium rates for the zero gap and insensitivity scenarios are very similar across different coverage horizons (Tables 2-5), indicating that active interest rate management achieves practically the same effect as sticking exclusively to interest rate insensitive assets and liabilities. The difference in the premium rates for $(-7, -3)$ and that for $(-3 \times \frac{L}{A}, -3)$ reflects the interest rate risk. The interest rate risk effect is quite substantial and is more pronounced (in a relative sense) for a lower-leverage insurer or over a shorter horizon.

Table 5 provides the fair premium rates by setting the interest rate risk premium to zero but maintaining the regulatory action of lowering both asset risk and underwriting intensity. These premium rates are slightly lower than those given in Table 4 but preserve the same general pattern. Recall that a negative λ actually implies a positive interest rate risk premium. A zero interest rate risk premium should therefore make the guaranty value lower for an insurer that is subject to interest rate risk. Indeed, these two tables confirm this intuition for they reveal a noticeable decline in the fair premium rate in the case of $(-7, -3)$ when we set the interest rate risk premium to zero. It is also not surprising to see no effect caused by the interest rate risk premium when both assets and liabilities are interest rate insensitive, i.e., for the $(0, 0)$ case. For the same reason, the effect of the interest rate risk premium is expected to be negligible for an insurer that employs interest rate risk management, i.e., for the $(-3 \times \frac{L}{A}, -3)$ case.

4.3.4 Mandatory control and rehabilitation effect

Three regulatory responses - lowering asset risk, lowering underwriting intensity and both - are considered and the results are presented in Tables 2, 3 and 4, respectively. We have also considered a controlled experiment for which regulatory responses are precluded. The results are presented in Table 4. Comparing the values in Table 4 with those in Tables 2 and 3 leads us to conclude that the joint regulatory response is more effective than the individual regulatory action of lowering asset risk or underwriting activity. It is also clear from comparing Tables 2 and 3 to the case of no regulatory action in Table 4 that individual regulatory actions do reduce the guaranty cost albeit rather marginally.

The tightness of the RBC standards is reflected in our model through the vigilance factor ρ. Table 6 shows that for an insurer with $A/L = 1.3$, the lower the regulatory vigilance factor the higher the guaranty cost is. Although we have only presented the results under one leverage ratio, it is clear that the same conclusion hold under other scenarios. In short, a tighter regulatory capital control indeed achieves an outcome that is consistent with its intended objective.

5 Conclusion

We have developed a model for measuring the cost of insurer default to the insurance guaranty fund by taking into account asset and interest rate risks, catastrophic losses and regulatory responses. Our model provides a stylized description of regulatory responses which proxies the practice mandated by the RBC standards under the current U.S. regulatory regime. Through the fair premium rate concept, we examine the cost to the guaranty fund in terms of an insurer's asset-liabilities characteristics and the level of regulatory vigilance.

Our model has interesting policy implications. For example, it provides a concrete way to begin the assessment of the intrinsic cost associated with a particular guaranty contract, and through which we can determine the *ex ante* aggregate liabilities to the guaranty fund posed by a pool of insurers. Although the current RBC standards are useful in maintaining a stable insurance market, the current practice of settling the policy liabilities on a post-assessment basis fails to reflect an individual insurer's characteristics beyond premium volume. The fair premium rate concept can thus be used to complement the current RBC standards toward establishing a stable insurance market coupled with a fairly-priced guaranty fund.

This multiperiod guaranty fund model offers a useful platform for future research in both theoretical and empirical dimensions. Here we contemplate a few possibilities. First, the model can be extended to incorporate the customer responses to an insurer entering rehabilitation. In the current model, one of the regulatory responses is to mandate a lower underwriting intensity, which is an adjustment to the rate but not the level. In contrast, a customer response is more in line with a level drop in insurance policies due to a sudden exodus upon learning the news of rehabilitation. This extension will add further richness to the trilateral bonding aspect of the current model. Second, this multiperiod model can be modified to deal with the effects of mergers/acquisitions either prior to or at the time of an insurer being placed under rehabilitation. Finally, this model is concrete enough for one to begin an empirical analysis of the fair premium rates across insurers in one and/or multiple jurisdictions before and after the adoption of the RBC standards.

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Table 1: Parameter definition and base values

Asset Parameters		Values
A	insurer's initial asset value	$1.1, 1.3, 1.5$
μ_A	drift parameter due to pure credit risk	irrelevant
η	underwriting intensity parameter	8%
κ	claim payments net of policy premium proceeds	0
ϕ_A	interest rate elasticity of asset	$-7, 0$
σ_A	volatility of credit risk	5%
q_u	upper bound of A/L ratio	1.5
Interest Rate Parameters		
r	initial instantaneous interest rate	6.13%
α	magnitude of mean reverting force	0.2249
m	long-run mean of interest rate	6.13%
υ	volatility parameter for interest rate	0.07
λ	market price of interest rate risk	-0.111
Liability Parameters		
L	insurer's initial liabilities	1
μ_L	drift parameter due to pure liability risk	irrelevant
ϕ_L	interest rate elasticity of liability	$-3, 0$
σ_L	volatility of pure liability risk	3%
θ	catastrophe event intensity	$0.33, 0.1$
μ_y	mean of logarithmic jump magnitude	-2.3075851
σ_y	standard deviation of logarithmic jump magnitude	0.1
Regulatory Parameters		
c_A	moral hazard intensity for credit risk	5%
c_U	moral hazard intensity for pure liability risk	8%
ρ	regulatory vigilance factor	1.1

Table 2: Premium rate δ_T in basis points with a T-year coverage horizon. (Lowering asset risk to zero for insurers under rehabilitation. All estimates are computed using 50,000 sample paths. Other parameter values are specified in Table 1.)

Interest Rate Elasticity (ϕ_A, ϕ_L)	$(-7, -3)$		$(-3 \times \frac{L}{A}, -3)$		$(0, 0)$	
Catastrophe Event Intensity $\theta =$	0.1	0.33	0.1	0.33	0.1	0.33
Initial Asset/Liability Position $(A/L = 1.5)$						
$\delta_{T=1}$	0.088	0.621	0.000	0.085	0.000	0.084
$\delta_{T=2}$	2.528	5.094	0.063	1.050	0.048	0.936
$\delta_{T=3}$	7.280	11.977	0.310	2.515	0.246	2.318
$\delta_{T=4}$	12.884	19.581	0.959	4.961	0.772	4.426
$\delta_{T=5}$	18.065	25.960	1.813	7.413	1.418	6.725
$\delta_{T=6}$	22.617	31.315	2.807	10.018	2.187	8.988
$\delta_{T=8}$	29.359	39.599	5.317	14.887	4.287	13.682
$\delta_{T=10}$	34.518	45.189	7.834	18.649	6.509	17.251
$A/L = 1.3$						
$\delta_{T=1}$	4.212	10.385	0.278	3.365	0.258	3.277
$\delta_{T=2}$	17.215	26.980	1.695	8.456	1.577	8.174
$\delta_{T=3}$	26.256	37.027	3.282	13.044	3.050	12.351
$\delta_{T=4}$	32.918	44.472	5.466	16.877	5.029	15.958
$\delta_{T=5}$	37.434	48.456	7.422	20.095	6.724	19.230
$\delta_{T=6}$	40.424	51.633	9.073	22.512	8.242	21.649
$\delta_{T=8}$	43.982	55.799	12.082	26.192	11.157	25.298
$\delta_{T=10}$	46.314	58.350	13.901	28.692	13.010	27.815
$A/L = 1.1$						
$\delta_{T=1}$	110.431	149.121	37.339	79.897	37.262	79.737
$\delta_{T=2}$	108.194	140.694	35.752	75.889	35.601	75.639
$\delta_{T=3}$	103.953	132.070	35.336	72.668	35.090	72.476
$\delta_{T=4}$	99.661	125.349	35.156	70.554	34.888	70.308
$\delta_{T=5}$	95.527	120.045	35.129	68.265	34.748	68.193
$\delta_{T=6}$	92.142	115.192	35.189	66.109	34.750	65.997
$\delta_{T=8}$	85.721	107.639	34.921	62.865	34.371	62.622
$\delta_{T=10}$	81.814	101.934	34.257	60.005	33.610	59.713

Table 3: Premium rate δ_T in basis points with a T-year coverage horizon. (Lowering underwriting intensity to zero for insurers under rehabilitation. All estimates are computed using 50,000 sample paths. Other parameter values are specified in Table 1.)						
Interest Rate Elasticity (ϕ_A, ϕ_L)	$(-7, -3)$		$(-3 \times \frac{L}{A}, -3)$		$(0, 0)$	
Catastrophe Event Intensity $\theta =$	0.1	0.33	0.1	0.33	0.1	0.33
Initial Asset/Liability Position ($A/L = 1.5$)						
$\delta_{T=1}$	0.088	0.621	0.000	0.085	0.000	0.084
$\delta_{T=2}$	2.556	5.218	0.059	1.077	0.048	0.956
$\delta_{T=3}$	7.417	12.283	0.351	2.717	0.279	2.505
$\delta_{T=4}$	13.471	20.216	1.191	5.381	0.921	4.898
$\delta_{T=5}$	18.647	26.323	2.294	8.083	1.822	7.487
$\delta_{T=6}$	23.048	31.725	3.617	10.821	2.914	9.739
$\delta_{T=8}$	29.633	39.733	6.641	15.772	5.559	14.461
$\delta_{T=10}$	34.501	44.923	9.480	19.462	8.187	18.129
$A/L = 1.3$						
$\delta_{T=1}$	4.212	10.385	0.278	3.365	0.258	3.277
$\delta_{T=2}$	17.967	27.660	2.081	9.306	1.900	8.934
$\delta_{T=3}$	27.447	37.904	4.263	14.459	3.988	13.906
$\delta_{T=4}$	33.992	45.387	7.359	18.745	6.938	18.037
$\delta_{T=5}$	38.083	49.287	9.694	22.049	9.148	21.262
$\delta_{T=6}$	40.919	51.957	11.775	24.226	11.074	23.490
$\delta_{T=8}$	43.937	55.536	15.018	27.536	14.287	26.788
$\delta_{T=10}$	46.093	57.552	16.699	29.563	16.068	28.901
$A/L = 1.1$						
$\delta_{T=1}$	110.431	149.121	37.339	79.897	37.262	79.737
$\delta_{T=2}$	114.204	145.314	45.969	82.845	45.783	82.617
$\delta_{T=3}$	109.831	135.995	47.654	79.759	47.500	79.666
$\delta_{T=4}$	104.338	128.217	46.804	77.070	46.777	79.920
$\delta_{T=5}$	99.328	121.646	45.707	73.628	45.578	73.565
$\delta_{T=6}$	95.266	116.478	44.792	70.639	44.549	70.578
$\delta_{T=8}$	88.257	108.065	42.764	66.193	42.435	66.046
$\delta_{T=10}$	83.876	102.290	40.670	62.658	40.400	62.426

Table 4: Premium rate δ_T in basis points with a T-year coverage horizon. (Two alternative actions for insurers under rehabilitation. All estimates are computed using $50,000$ sample paths. Other parameter values are specified in Table 1.)

	No action		Lowering asset risk and underwriting intensity to zero					
(ϕ_A, ϕ_L)	$(-7,-3)$		$(-7,-3)$		$(-3\times\frac{L}{A},-3)$		$(0,0)$	
$\theta =$	0.1	0.33	0.1	0.33	0.1	0.33	0.1	0.33
Initial Asset/Liability Position ($A/L = 1.5$)								
$\delta_{T=1}$	0.088	0.621	0.088	0.621	0.000	0.085	0.000	0.084
$\delta_{T=2}$	2.582	5.291	2.503	5.032	0.063	1.035	0.048	0.921
$\delta_{T=3}$	7.613	12.623	7.096	11.674	0.301	2.457	0.239	2.268
$\delta_{T=4}$	13.967	20.991	12.429	18.922	0.922	4.769	0.747	4.264
$\delta_{T=5}$	19.553	27.541	17.254	24.808	1.706	7.059	1.341	6.391
$\delta_{T=6}$	24.382	33.419	21.408	29.727	2.595	9.408	2.038	8.430
$\delta_{T=8}$	31.633	42.324	27.466	37.263	4.779	13.785	3.878	12.604
$\delta_{T=10}$	37.074	48.186	32.031	42.300	6.829	17.003	5.672	15.683
$A/L = 1.3$								
$\delta_{T=1}$	4.212	10.385	4.212	10.385	0.278	3.365	0.258	3.277
$\delta_{T=2}$	18.442	28.306	16.801	26.410	1.658	8.273	1.550	7.996
$\delta_{T=3}$	28.620	39.373	25.231	35.691	3.149	12.471	2.921	11.878
$\delta_{T=4}$	35.802	47.536	31.223	42.414	5.111	15.956	4.674	15.140
$\delta_{T=5}$	40.472	51.978	35.171	46.021	6.768	18.783	6.140	17.936
$\delta_{T=6}$	43.754	55.066	37.710	48.712	8.074	20.841	7.400	19.954
$\delta_{T=8}$	47.338	59.023	40.630	52.200	10.425	23.860	9.673	22.963
$\delta_{T=10}$	49.854	61.577	42.626	54.411	11.846	25.711	11.018	25.012
$A/L = 1.1$								
$\delta_{T=1}$	110.431	149.121	110.431	149.121	37.339	79.897	37.262	79.737
$\delta_{T=2}$	117.144	148.288	105.735	138.078	34.769	74.222	34.631	73.974
$\delta_{T=3}$	114.321	140.358	100.137	128.158	33.433	69.869	33.251	69.705
$\delta_{T=4}$	109.548	133.141	95.076	120.695	32.401	66.950	32.288	66.720
$\delta_{T=5}$	104.784	127.037	90.528	114.980	31.805	64.125	31.583	64.028
$\delta_{T=6}$	100.945	122.006	86.927	110.015	31.335	61.711	31.069	61.641
$\delta_{T=8}$	94.029	113.735	80.467	102.395	30.310	57.905	29.812	57.792
$\delta_{T=10}$	89.811	107.921	76.619	96.719	29.166	54.919	28.747	54.816

Table 5: Premium rate δ_T in basis points with a T-year coverage horizon when the interest rate risk premium is set to zero. (Lowering both asset risk and underwriting intensity to zero for insurers under rehabilitation. All estimates are computed using $50,000$ sample paths. Other parameter values are specified in Table 1.)						
Interest Rate Elasticity (ϕ_A, ϕ_L)	$(-7, -3)$		$(-3 \times \frac{L}{A}, -3)$		$(0, 0)$	
Catastrophe Intensity $\theta =$	0.1	0.33	0.1	0.33	0.1	0.33
Initial Asset/Liability Position $(A/L = 1.5)$						
$\delta_{T=1}$	0.073	0.569	0.000	0.084	0.000	0.084
$\delta_{T=2}$	1.989	4.326	0.061	1.026	0.048	0.921
$\delta_{T=3}$	5.461	9.822	0.290	2.433	0.239	2.268
$\delta_{T=4}$	9.405	15.711	0.890	4.662	0.747	4.264
$\delta_{T=5}$	12.919	20.432	1.616	6.923	1.341	6.391
$\delta_{T=6}$	16.069	24.273	2.462	9.233	2.038	8.430
$\delta_{T=8}$	20.523	30.532	4.518	13.469	3.878	12.604
$\delta_{T=10}$	23.979	34.734	6.436	16.650	5.672	15.683
$A/L = 1.3$						
$\delta_{T=1}$	3.828	9.846	0.277	3.360	0.258	3.277
$\delta_{T=2}$	14.638	24.143	1.645	8.243	1.550	7.996
$\delta_{T=3}$	21.393	31.812	3.105	12.345	2.921	11.878
$\delta_{T=4}$	26.105	37.366	5.033	15.797	4.674	15.140
$\delta_{T=5}$	28.902	40.394	6.651	18.595	6.140	17.936
$\delta_{T=6}$	30.656	42.499	7.926	20.666	7.400	19.954
$\delta_{T=8}$	32.503	44.951	10.325	23.627	9.673	22.963
$\delta_{T=10}$	33.893	46.331	11.717	25.481	11.018	25.012
$A/L = 1.1$						
$\delta_{T=1}$	106.565	145.475	37.331	79.887	37.262	79.737
$\delta_{T=2}$	99.665	132.429	34.739	74.209	34.631	73.974
$\delta_{T=3}$	92.801	121.473	33.403	69.907	33.251	69.705
$\delta_{T=4}$	87.015	113.673	32.370	66.988	32.288	66.720
$\delta_{T=5}$	81.974	107.437	31.747	64.105	31.583	64.028
$\delta_{T=6}$	78.089	101.933	31.277	61.675	31.069	61.641
$\delta_{T=8}$	71.368	94.085	30.164	57.896	29.812	57.792
$\delta_{T=10}$	67.199	88.125	29.065	54.845	28.747	54.816

Table 6: Premium rate δ_T in basis points with a T-year coverage horizon under different regulatory vigilance levels. (Lowering both asset risk and underwriting intensity to zero for insurers under rehabilitation. All estimates are computed using $50,000$ sample paths. Other parameter values are specified in Table 1.)				
Initial Asset/Liability Position ($A/L = 1.3$)				
Regulatory Vigilance Ratio $\rho =$	1.3	1.2	1.1	1
Interest Rate Elasticity $(\phi_A, \phi_L) =$ (-7,-3),Catastrophe Intensity $\theta = 0.1$				
$\delta_{T=1}$	4.212	4.212	4.212	4.212
$\delta_{T=2}$	13.185	14.382	16.801	18.442
$\delta_{T=3}$	18.788	21.201	25.231	28.620
$\delta_{T=4}$	23.016	26.174	31.223	35.802
$\delta_{T=5}$	25.695	29.457	35.171	40.472
$\delta_{T=6}$	27.333	31.502	37.710	43.754
$\delta_{T=7}$	28.516	32.944	39.338	45.479
$\delta_{T=8}$	29.290	33.813	40.630	47.338
$\delta_{T=9}$	29.960	34.810	41.556	48.511
$\delta_{T=10}$	30.609	35.557	42.626	49.854