



## Can insurers pay for the “big one”? Measuring the capacity of the insurance market to respond to catastrophic losses

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### Abstract

This paper presents a theoretical and empirical analysis of the capacity of the US property–liability insurance industry to finance catastrophic property losses in the \$100 billion range. In our theoretical analysis, we show that the sufficient condition for capacity maximization, given a level of total resources in the industry, is for all insurers to hold a net of reinsurance underwriting portfolio which is perfectly correlated with aggregate industry losses. This result leads to a natural definition of industry capacity as the amount of industry resources that are deliverable conditional on an industry loss of a given size. Estimating capacity using insurer financial statement data, we find that the industry could adequately fund a \$100 billion event. However, such an event would cause numerous insolvencies and severely destabilize insurance markets. © 2002 Elsevier Science B.V. All rights reserved.

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## 1. Introduction

Catastrophic events such as the Northridge earthquake and Hurricane Andrew each cost the insurance industry in excess of \$10 billion. While most insured losses were paid, each event resulted in insurer insolvencies and illustrated the potential stress facing insurance markets from a major catastrophe. Hurricane Andrew, which cost the insurance industry about \$19 billion,<sup>3</sup> would have been much more severe had its path veered slightly to hit Miami. Moreover, scenarios constructed by catastrophe modeling firms suggest the feasibility of a \$76 billion hurricane in Florida, a \$21 billion Northeast hurricane, a \$72 billion California earthquake and a \$101 billion New Madrid earthquake.<sup>4</sup> At first glance, it might appear that the insurance industry would be able to pay for such mega catastrophes. The US property–liability insurance industry’s equity capital is approximately \$350 billion. This capital is potentially available to pay for losses which exceed the reserves (established for their payment from premiums). However, the reality would be different; depending on the distribution of damage and the spread of coverage, many insurers would become insolvent.<sup>5</sup> Technically, this problem should be solved by the state operated insurance guaranty funds which re-allocate defaulted liabilities among solvent insurers. But these only operate within small limits,<sup>6</sup> and even this burden would stretch the already strained resources of surviving insurers. Thus, the prospect of a mega-catastrophe brings the real threat of widespread insurer failures and unpaid claims. Moreover, surviving insurers would be so depleted of surplus, and thus over-levered, they would have to reduce the future sale of all types of property–liability insurance causing price increases and severe availability problems.

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<sup>3</sup> Swiss Re (2000).

<sup>4</sup> These figures were obtained from Risk Management Solutions. Similar figures have been projected by other firms, including Applied Insurance Research. These estimates relate only to the insured losses. The total damage, including infrastructure, would be higher. For hurricane losses a substantial portion of total losses is likely to be insured. However, for earthquake losses many properties are not insured and others carry high deductibles. Thus, for earthquake losses the total societal loss could be multiples of this estimate.

<sup>5</sup> Insurers can spread their liabilities to other insurers through reinsurance. In principle, the effects of catastrophes can be spread through the worldwide reinsurance market. In practice the available capacity of reinsurers is limited even though it has increased significantly since Hurricane Andrew (Cummins and Weiss, 2000). Although estimates vary, it seems clear that a substantial gap exists between existing reinsurance coverage and a catastrophic loss exceeding the \$15–20 billion range. For example, Swiss Re (1997) estimated that reinsurers would pay 39% of a US once-in-100-year catastrophe loss such as a \$56 billion hurricane or a \$65 billion earthquake in California. The Swiss Re study estimated a worldwide total of \$53 billion in catastrophe excess of loss reinsurance in place in 1997. See also Guy Carpenter (1998).

<sup>6</sup> Guaranty funds limit the amount paid for any given loss, typically to \$300,000, as well as limiting the annual assessment against solvent insurers to 2–3% of premiums.

These scenarios have led both state and federal governments to contemplate legislative solutions involving the government as a reinsurer and/or enlisting capital markets to provide catastrophe financing (Lewis and Murdock, 1996; Cummins et al., 1999). Moreover, the vulnerability of insurance markets has led to financial market innovations such as catastrophic loss derivatives. Among the new financial instruments that have been introduced are CAT bonds in which borrowers contract for some degree of debt forgiveness in the event of a predefined catastrophe. Another innovative instrument is the CatEPut in which re-capitalization can be achieved after a catastrophe by the firm's exercising a put option on its own stock. Also, in the absence of adequate reinsurance, insurers have sometimes swapped their catastrophe exposures.

In this paper, we conduct a theoretical and empirical analysis of the capacity of the insurance industry to respond to catastrophic events. Given appropriate technical (weather, seismic, etc.) data, plus descriptions of insured properties for each insurer, one can estimate an insurer response for any given event such as a force 5 hurricane hitting Miami or an 8.2 earthquake in San Francisco. Such scenario analysis is carried out by modeling firms such as Applied Insurance Research and Risk Management Solutions. However, there is a very large number (approaching infinite) of potential catastrophe scenarios, and the data demands for conducting such an analysis for the entire insurance industry are enormous. Moreover, while such scenarios are valuable for planning at the firm level, they provide too much detail for assessing the efficiency of the insurance market in spreading risk. Rather, we seek a more general response function. We estimate the distributional characteristics of catastrophic losses and allocate such losses to individual insurers using correlations and financial data. The result is an option-like function that defines the estimated deliverable insurance payments conditional on any given size of aggregate catastrophic loss and projects the number of insurer insolvencies that would result.

Such a measure of capacity rests on two broad components; size and diversification – how much equity or “surplus” is available and how effectively the riskiness of insurance losses is spread though the insurance market. The traditional instrument to spread risk between insurers is reinsurance. By buying and selling “options” on their portfolios with each other, and to specialized reinsurers, insurers can change the risk characteristics of their portfolios. In a paper that anticipated the capital asset pricing model, Borch (1962), showed that the value maximizing trades would leave all insurers holding net of reinsurance portfolios defined solely on the market aggregate loss and that insurance would be priced solely on the correlation with this aggregate portfolio. We show that the distribution of insurance liabilities which minimizes insolvencies, and thereby maximizes payments to policyholders, is similar to Borch's equilibrium. However, this structure also provides a framework for measuring the available capacity of the industry to respond to major catastrophes.

The paper is organized as follows: Section 2 sets forth our theory of industry capacity and derives the option-like model used in our capacity estimation. Section 3 discusses sample selection and our empirical approach to estimating capacity. Section 4 presents the results, and Section 5 concludes.

## 2. Diversification and the mutuality principle

In this section, we develop a theoretical model of capacity in an insurance market. We begin by examining a baseline case in which the liabilities in an insurance market are distributed amongst insurers so as to maximize payouts to policyholders for any given loss scenario. The baseline case establishes a basic relationship between the capacity of the insurance industry to respond to catastrophic loss experience and the correlation structure of its liabilities. We then derive a measure of capacity which is parameterized by these correlations together with other firm and market features.

### 2.1. Definition of insurance capacity

We examine a baseline case in which the liabilities in an insurance market are distributed amongst insurers so as to maximize payouts to policyholders for any loss scenario. This base case is useful for defining industry capacity and also provides a yardstick for measuring capacity. In the baseline case, insolvencies will be minimized for any given level of industry losses and thus actual payments to policyholders will be maximized.

It is well known that in a market in which risk bearing is costly to firms but where transacting between firms is costless, the Pareto optimal risk sharing arrangement is one in which the industry “mutualizes” its risk in the sense that all insurers hold the same net (after reinsurance) liability portfolio. This result, due to Borch (1962), is similar to (and preceded) the capital asset pricing model. According to Borch, the Pareto optimal reinsurance arrangement is one in which each insurer holds a net (after reinsurance) portfolio which is a proportionate claim on total insured losses,  $L$ . This result is equivalent to the CAPM proposition that each investor will hold the market portfolio. The implication is that all insurers portfolios are perfectly correlated after reinsurance transactions have been exploited. After all possibilities for diversification through reinsurance are exhausted, insurers will hold the same loss portfolio though the scale may differ. The aggregate loss for the market is  $\sum L_i \equiv L$ , where  $L_i$ , the loss sustained by insurer  $i$ . The riskiness of the aggregate portfolio will depend on the total number of individual policies insured,  $n$ , and on their correlations. If the number of policyholders is very large and the policy correlations are low then, by the law of large numbers,  $L$  will have little risk ( $\sigma(L/n) \rightarrow 0$  as  $n \rightarrow \infty$ , where  $\sigma(L/n)$  the standard deviation of

average losses per policy). But with small  $n$  and/or high correlation among insured losses,  $L$  will have higher risk.

To address the implications of limited liability, first consider the terminal value of equity,  $T_i$ , of an insurer,  $i$ , in a simple one period model:

$$T_i = \text{MAX}\{(P_i + Q_i^0)(1 + r) - \alpha_i L; 0\}, \tag{1}$$

where  $Q_i^0$  is opening equity or “surplus” for insurer  $i$ ,  $P_i$  is premium income net of expenses, and  $r$  is the rate of return on investments, assumed to be riskless. Insurer  $i$  is assumed to hold a proportionate share  $\alpha_i$  of the market insurance portfolio so that its losses  $L_i = \alpha_i L$ . For simplicity, assume that the market is competitive, thus  $P_i = E(L_i)/(1 + r)$ . Denoting  $Q_i = Q_i^0(1 + r)$ , terminal equity is re-stated as

$$T_i = \text{MAX}\{E(L_i) + Q_i - L_i; 0\}. \tag{1'}$$

Now consider the implications of limited liability for policyholders. The amount which insurer “ $i$ ” can pay to policyholders,  $L_i^p$ , is the minimum of the face value of its liability or its financial resources which, in this model are the sum of net premiums and equity capital  $E(L_i) + Q_i$ , i.e.,

$$L_i^p = \text{MIN}\{L_i; E(L_i) + Q_i\}. \tag{2}$$

If there is a bad draw from the loss distribution, i.e., a catastrophic loss, the ability of the insurer to pay the unexpected loss  $L_i - E(L_i)$  depends on its equity capital  $Q_i$ . If we scale up this problem, then the ability of the market to respond to unexpected losses depends on the total industry capital, but also on how the liabilities and surplus are distributed across insurers. We will use this concept to define and measure market capacity.

If we compare this limited liability world with Borch’s equilibrium, there is an apparently stark contrast. In Borch’s world, insurers are risk averse and will gain from risk sharing through reinsurance transactions. In our limited liability model, insurers own a put option on  $L_i$  with strike price  $E(L_i) + Q_i$ . The value of this option is increasing in the variance of the underlying asset (in this case the loss portfolio). Thus, apparently, insurers would not engage in risk reducing reinsurance transactions. We can add more structure to resolve this difference by allowing premium rates to depend on insurer risk.<sup>7</sup> This additional structure is not necessary for our present task, but it does focus our attention on what the payouts to policyholders would be when insurers are perfectly diversified as shown by Borch.

Consider a Borch equilibrium in which each insurer, “ $i$ ” holds a share  $\alpha_i$  of  $L$  and assume that each insurer’s surplus is scaled to its share of aggregate loss. The first implication is that the aggregate terminal equity of insurers will be the

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<sup>7</sup> See Doherty and Tinic (1981).

difference between the industry equity  $\sum_i Q_i$  and the unexpected industry loss  $L - E(L)$ , as shown in Eq. (3a) below. The second implication is that the industry's whole surplus will be available to meet unexpected losses. Thus, the amount of aggregate losses that will be paid to policyholders,  $L^p$ , will be the minimum of the face value of losses  $L$  and the industry's total resources  $E(L) + Q$ , as shown in Eq. (3b).

$$\begin{aligned} \sum_{i=1}^N T_i &= \text{MAX} \left\{ \sum_{i=1}^N [\alpha_i E(L) + Q_i - \alpha_i L]; 0 \right\} \\ &= \text{MAX} \left\{ E(L) + \sum_{i=1}^N Q_i - L; 0 \right\}, \end{aligned} \quad (3a)$$

$$\sum_{i=1}^N L_i^p = \text{MIN} \left\{ L; E(L) + \sum_{i=1}^N Q_i \right\}, \quad (3b)$$

where  $N$ , the total number of insurers in the market. Currently, the US property-liability insurance industry's equity capital is about \$350 billion. If our model applied to the industry, the entire amount of the equity capital would be available to pay unexpected losses. In effect, with perfect diversification, the industry acts as a single firm. No one firm would become insolvent until the entire industry capital is exhausted and, at this point, all firms would simultaneously become insolvent. This equilibrium distributes industry liabilities and resources in a way that maximizes payouts to policyholders.

**Definition.** For any configuration of losses for which insurers are liable, the capacity of the insurance market is the proportion of those liabilities that is deliverable given the financial resources of firms on whom the losses fall and given all arrangements (such as reinsurance, guarantee funds, etc.) for re-allocating those losses among insurers.

In the equilibrium considered, all industry surplus would be accessible by policyholders.

## 2.2. Conditions for capacity maximization

Consider each insurer's aggregate loss as the sum of its catastrophe exposure and its idiosyncratic risk. Part of the individual insurer loss,  $d_i$ , is idiosyncratic and diversifiable; i.e.,  $\text{COV}(d_i, d_j) = 0 \forall i \neq j$ . The remaining part of the insurer's loss is catastrophe risk in the sense that all insurers are exposed to highly correlated losses,  $L_U$ , from events such as hurricanes and earthquakes. The proportion of the total pool of catastrophe losses written by insurer "i" is  $c_i$ . Thus, the loss of insurer  $i$  is

$$L_i = c_i L_U + d_i. \tag{4}$$

Given that  $\sum L_i$  must equal the aggregate industry losses,  $L \equiv L_U + D$  (where  $D \equiv \sum_i d_i$  is the total industry diversifiable losses), then  $\sum c_i = 1$ . The essential characteristic of diversifiable risk is that it will tend to zero if a large enough number of policies is insured. To provide a rationale for a reinsurance market, we assume that any individual insurer holding  $n_i$  policies is insufficiently diversified to secure this risk elimination, but the total insurance market having  $\sum_i n_i \equiv n$  policies does effectively eliminate risk, i.e.,

$$\sigma\left(\frac{D}{n}\right) \approx 0; \quad \sigma\left(\frac{d_i}{n_i}\right) \not\approx 0; \quad \sigma\left(\frac{c_i L_U}{n_i}\right) \not\approx 0; \quad \sigma\left(\frac{L_U}{n}\right) \not\approx 0. \tag{5}$$

The first expression in Eq. (5) says that diversifiable risk can be substantially eliminated by diversification across the marketplace. The second expression says that each individual insurer’s endowment of potentially diversifiable exposures is not sufficient to eliminate this risk (i.e., it does not have sufficient policies to fully exploit the law of large numbers). The third and fourth expressions in Eq. (5) assert that the risk of  $L_U$  is not diversifiable (i.e., losses are positively correlated), even in the limit. The third expression is particularly important in providing a rationale for insurance. By definition of  $d_i$  and  $c_i L_U$ , the former can be reduced through further risk spreading whereas the latter cannot.

We now develop the following necessary condition for optimal risk sharing behavior:

**Proposition.** *A necessary condition for the average industry capacity per policyholder,  $\sum_i E(L_i^p|n)$ , to be maximized is that all firms hold a net of reinsurance portfolio which is proportional to  $L_U$  and  $D$ .*

The proposition requires that all insurers hold portfolios of the form  $\alpha_i L = c_i L_U + k_i D$  where  $\alpha_i$ ,  $c_i$ , and  $k_i$  are firm specific constants.<sup>8</sup> Suppose that this were not true. Then at least one insurer would hold a portfolio containing

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<sup>8</sup> The reinsurance structure that maximizes industry capacity ( $\alpha_i L = c_i L_U + k_i D, \forall i$ ) is similar to the Pareto optimal reinsurance market identified by Borch (1962). The similarity is more pronounced when it is noticed that, since  $D$  is diversifiable, the value of  $k_i$  makes little difference to the availability of capital to pay catastrophic losses. Thus, one can consider the special case in which  $\alpha_i = k_i$ . However, even for this special case, our result and that of Borch are not necessarily identical. While, in both results, insurers’ loss portfolios are defined solely on  $L$ , we rely on a maximization of aggregate dollar capital whereas Borch relied on expected utility maximizing trades between risk averse insurers. The non-linearity in our result comes from the truncating effects of insolvency whereas the non-linearity in Borch’s reinsurance market comes from the parameters of insurer utility functions.

some idiosyncratic risk; i.e.,  $\alpha_i L_U + d_i$ , where  $d_i \neq k_i D$ . Since  $D \equiv \sum_i d_i$ , the existence of one insurer holding  $c_i L_U + d_i$  implies that all other insurers must hold in total

$$(1 - c_i)L_U + D - d_i = \sum_{j \neq i}^N c_j L_U + D - d_i$$

which cannot be of the form

$$\sum_{j \neq i}^N c_j L_U + \sum_{j \neq i}^N k_j D$$

since  $d_i \neq k_i D$  and  $D \equiv \sum_i d_i$ .<sup>9</sup> Thus, at least one other insurer must hold a portfolio of the form  $c_j L_U + d_j$  where  $d_j \neq k_j D$ . Of the universe of insurers  $M$  we define a subset  $m_1$  having such “undiversified” portfolios  $\alpha_i L_U + d_i$  and subset  $m_2$  having “diversified” portfolios of the form  $\alpha_j L_U + k_j D$ . Since

$$\left(1 - \sum_{j \in m_2} k_j\right) D = \sum_{i \in m_1} d_i$$

then the following mutual exchange is possible. All type  $m_1$  insurers pool their diversifiable risk which leads to an aggregate  $m_1$  diversifiable liability of  $(1 - \sum_{j \in m_2} k_j) D$ . Now define a set of weights  $k'_i$  and apportion this aggregate liability over  $m_1$  insurers such that each assumes a liability of

$$k'_i \left(1 - \sum_{j \in m_2} k_j\right) D = k_i D \quad \text{since } k'_i \equiv k_i \left(\frac{1}{1 - \sum_{j \in m_2} k_j}\right) \quad \text{and} \quad \sum_{j \in m_1} k'_j = 1.$$

These conditions ensure that  $\sum k_i = 1$  (i.e., that diversifiable risk  $D$  is fully allocated over all insurers). Since the only requirement placed on  $k'_i$  is that it sum to unity, these weights can be chosen such that the  $E(d_i) = E(k_i D)$ . Thus, these transactions will leave all  $m_2$  insurers unaffected and will leave the expected face value of liability of all  $m_1$  unchanged. However, since  $\sigma(d_i/n_i) > 0$ ; and  $\sigma(k_i D/n_i) \Rightarrow 0$ , these transactions are mean preserving, and risk reducing, for all  $m_1$  insurers. Now since the payable loss of any insurer is a short position in a put option, its value will increase as its standard deviation is

<sup>9</sup> To see this, consider that all other insurers did hold portfolios of the form  $\sum_{j \neq i} \alpha_j L_U + \sum_{j \neq i} k_j D$ . Thus the total of the diversifiable risk portfolios of all insurers would be: (a)  $D = \sum_{j \neq i} k_j D + d_i$ . This can be re-stated as (b)  $D = \sum_{j \neq i} k_j D + k_i D - k_i D + d_i = \sum_j k_j D + (d_i - k_i D)$  which is equal to (c)  $D = D + (d_i - k_i D)$  since  $\sum_j k_j = 1$ . However, since  $d_i \neq k_i D$ ; then (c), and therefore (a), is contradicted.

reduced. Consequently, these transactions will leave  $E(L_i^p/n)$ , where  $L_i^p$  is defined by Eq. (3b), unchanged for all  $m_2$  insurers but increased for all  $m_1$  insurers. As a result, aggregate available industry capacity  $\sum_i E(L_i^p/n)$  will be increased.

The proposition shows the necessary conditions for capacity maximization. The sufficient conditions concern the relationship between the liability allocation,  $\alpha_i$ , and the and the distribution of surplus,  $Q_i$ , across insurers. The effect of surplus will become important in the capacity measures derived in the next section.

**Corollary.** *When the necessary conditions for maximization of capacity per policyholder  $\sum_i E(L_i^p/n)$  are satisfied, all insurers will hold net of reinsurance portfolios  $L_i$  that are perfectly correlated with aggregate industry losses,  $L$ .*

Note that  $\text{COV}(L_i, L) = E\{[c_i(L_U - E(L_U)) + (d_i - E(d_i))][L - E(L)]\}$  which can be simplified to  $E\{[c_i(L_U - E(L_U))][L - E(L)]\}$  since  $d_i$  is independent of  $L$  by assumption. Using  $\text{COV}(D, L) = 0$  and  $L = L_U + D$ , we can write;  $\sigma^2(L) = E\{[L_U - E(L_U)][L - E(L)]\}$ . Thus,  $\text{COV}(L_i; L) = c_i\sigma^2(L)$ . Proof of the corollary follows immediately from the proposition noting that  $\text{COV}(L_i, L) = c_i\sigma^2(L)$  and that  $c_i$  and  $k_i$  are constants.

The corollary shows that each insurer must hold a net portfolio which is perfectly correlated with the aggregate insurable loss  $L$  to maximize capacity. This will provide a yardstick for measuring capacity. Since  $\alpha_i L = c_i L_U + k_i D$  maximizes capacity for a given initial industry surplus  $Q$ , and since this result is characterized by perfect correlation between all  $L_i$  and  $L$ , the actual correlations will provide a measure of capacity utilization.

Various frictions can frustrate the conditions described in the proposition and corollary. In addition to factors that limit firm size, reinsurance and other insurer hedges are costly. Froot and O'Connell (1996) estimated the cost of catastrophe reinsurance from the complete set of contracts brokered by the largest reinsurance broker. The transaction cost, ((price – expected loss)/expected loss), ranges between about 10% and 140% from 1970–1995. In the last decade of the series, the average transaction cost is about 65%. Several explanations can be given for this high cost including information asymmetries about the parameters of the loss distribution and the value of losses sustained from a given catastrophe, moral hazard, and excessive rent taking. Another explanation for incomplete diversification is that shareholders may seek to expropriate wealth from policyholders by choosing a high risk financial structure (Myers, 1977; Doherty and Tinic, 1981). This expropriation will be mitigated by reputation effects and where the policyholders and/or their agents can monitor the financial condition and reinsurance purchases of their insurers. We now examine the relationship between capacity, correlations between insurer losses, and the financial structure of insurers.

2.3. Correlations and capacity utilization for a given catastrophic loss

Our task is to estimate the industry’s ability to respond to abnormal loss experience defined by Eq. (3b). This is the industry response conditional on industry losses of any given size  $L$ . The response function is illustrated in Fig. 1. The horizontal axis measures possible values for aggregate insurance industry losses, and the vertical axis measures the *expected* payout of all firms combined. Consider two possible loss scenarios: first, a California earthquake that causes an industry loss of \$30 billion above the expected loss  $E(L)$  and, second, a combination of a Florida hurricane of \$20 billion and automobile losses that are \$10 billion above expectations. Both scenarios lead to industry losses that are \$30 billion above the expected value ( $E(L) + 30$ ). But the scenarios would impact different insurers and could lead to different numbers of insolvencies depending on the distribution of coverage across insurers. For example, the expected payout in the first scenario might be  $W$  which is very low because much of the California earthquake coverage is from local insurers that are poorly diversified and poorly capitalized. However, the second scenario might be spread more evenly over firms, with a payout shown as  $Y$ .

Points  $W$  and  $Y$  are the conditional responses which are described below in Eqs. (7)–(9). These are only two of many potential configurations that could result in industry losses of \$30 billion above expected value. The average of all possible payouts for all feasible scenarios which sum to \$30 billion above expected loss is denoted  $X$ . This value,  $X$ , is the conditional response, i.e., the expected payout of the industry conditional on an industry loss of  $E(L) + 30$

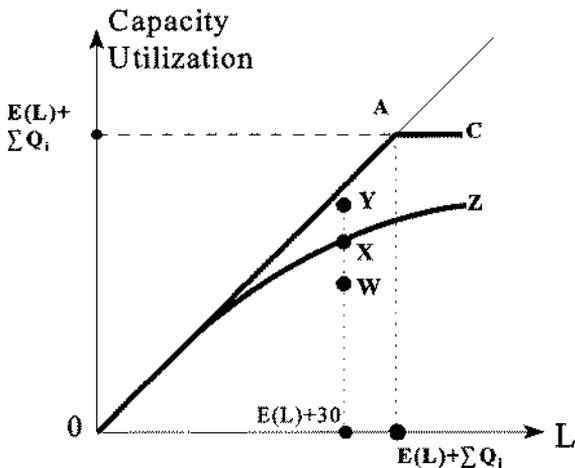


Fig. 1. Capacity utilization. *Note:* The line  $OAC$  represents maximum capacity utilization. The line  $OZ = E(L) + \sum Q_i - \sum E(T_i|L)$  represents estimated capacity utilization.

billion. The locus of all such conditional payouts is the response function which is shown as OZ. Notice that OZ lies at or below the 45° line and, we postulate, will diverge from the 45° line as loss realizations increase. The divergence implies that insolvencies will increase disproportionately with losses as more and more insurers are stressed and that failures are passed through the market via reinsurance thus causing “knock on” insolvencies.

It is useful to start with the expected terminal equity of insurer *i*:

$$E\left(\frac{T_i}{n_i}\right) = \left(\frac{1}{n_i}\right) \int_0^{Z_i} [E(L_i) + Q_i - L_i]f(L_i) dL_i, \tag{6}$$

where  $Z_i = E(L_i) + Q_i$ . To derive the conditional response function note that the aggregate expected terminal equity for the industry, conditional on industry losses of *L*, is

$$\sum_{i=1}^N E(T_i|L) = \sum_{i=1}^N \int_0^{Z_i} [E(L_i) + Q_i - L_i]f(L_i|L) dL_i. \tag{7}$$

This value is shown in Fig. 1 as the distance between the horizontal line beginning at  $E(L) + \sum Q_i$  on the vertical axis and the response function OZ. Thus, the response function can be defined as  $R|L \equiv E(L) + \sum Q_i - \sum_i E(T_i|L)$ .

To estimate the response function, it is necessary to make distributional assumptions about *L*. Using the normal distribution and the properties of conditional moments, the response function becomes:<sup>10</sup>

$$E(T_i|Q_i, L) = (E(L_i) + Q_i - \mu_{L_i|L})N\left[\frac{E(L_i) + Q_i - \mu_{L_i|L}}{\sigma_{L_i|L}}\right] + \sigma_{L_i|L} \frac{1}{\sqrt{2\pi}} e^{-(1/2)((E(L_i)+Q_i-\mu_{L_i|L})/\sigma_{L_i|L})^2}, \tag{8}$$

where

$$\mu_{L_i|L} = \mu_i + \frac{\rho_i \sigma_i}{\sigma_L} (L - \mu_L) \quad \text{and} \quad \sigma_{L_i|L}^2 = \sigma_i^2 (1 - \rho_i^2),$$

where  $\mu_i = E(L_i)$ ,  $\mu_L = E(L)$ , and  $\rho_i$  is the correlation coefficient between  $L_i$  and *L*. Not surprisingly, this formulation resembles an option pricing model.<sup>11</sup> The response function is

<sup>10</sup> Derivations of Eqs. (8) and (9) are available from the authors.

<sup>11</sup> However, it is important to point out that we are not pricing an option in the usual sense by using a risk-neutralized probability density function. Rather, we are calculating a conditional expected value. Nor are we asserting that insurance risk can be hedged by forming a replicating portfolio.

$$\begin{aligned}
 R_i|L &= E(L_i) + Q_i - E(T_i|Q_i, L) \\
 &= (E(L_i) + Q_i)N(-C_i) + \mu_{L_i|L}N(C_i) - \sigma_{L_i|L}n(C_i),
 \end{aligned}
 \tag{9}$$

where

$$C_i = \frac{E(L_i) + Q_i - \mu_{L_i|L}}{\sigma_{L_i|L}},$$

$N(\cdot)$  = the standard normal distribution function, and  $n(\cdot)$  = the standard normal density function. Note that  $R_i|L = f[E(L_i), E(L), \sigma(L_i), \sigma(L), Q_i, \rho_i|L]$ . Thus, we can measure the capacity of the industry for any industry loss  $L$ , as a function of two industry variables  $\{E(L), \sigma(L)\}$  and four firm variables  $\{E(L_i), \sigma(L_i), \rho_i, Q_i\}$ .<sup>12</sup> Comparative statics analysis of the response function (Eq. (9)) reveals that the expected response value is decreasing in  $\sigma_i$  and increasing in  $\rho_i$ , i.e., industry capacity is inversely related to  $\sigma_i$  and directly related to  $\rho_i$ . Intuitively, this occurs because the value of the insurer's option to default is increasing in  $\sigma_i$  and because the industry is closer to Borch's ideal equilibrium (the 45° line in Fig. 1) the higher are the  $\rho_i$ .

### 3. Measuring the capacity of the US insurance industry

In this section we develop estimates of response functions for the US property–liability insurance industry by selecting samples of insurers and estimating the parameters of Eq. (9). The response functions are then calculated for various values of  $L$ , the total industry loss. The objective of the analysis is to determine the ability of the US insurance industry to respond to catastrophic losses and to measure the efficiency of the industry in spreading risk across the market. This section discusses the technique we use to measure industry efficiency as well as sample selection and parameter estimation. The results are presented in Section 4.

<sup>12</sup> Alternatively, the response function can be estimated under the assumption that firm and industry losses are jointly lognormal (derivation available from the authors). However, if the  $L_i$  are lognormally distributed,  $L_i$  and  $L$  cannot be jointly lognormal, because sums of lognormals are not lognormal. Hence, the lognormal response function is only valid as an approximation. In experimenting with the lognormal response function we found that the results were generally consistent with those obtained using the normal response function. However, the results using the lognormal function were extremely sensitive to assumptions made to apply the function as an approximation as opposed to an exact result. Accordingly, the lognormal results are not as reliable as the normal distribution results and hence are not reported in the paper.

### 3.1. Measuring industry efficiency

Recall that in a fully efficient insurance market, the industry responds to losses as if it were a single firm. The response function for an efficient market is thus given by the line  $0AC$  in Fig. 1, i.e., an efficient insurance industry would pay 100% of all losses up to the point when all industry resources are exhausted. Thus, one measure of market inefficiency is the magnitude of the wedge between the fully efficient response function and the actual industry response function represented by the line  $0Z$  in Fig. 1. We measure the area of the wedge bordered by line segment  $0A$ , the response curve  $0Z$ , and the dotted vertical line segment originating at the point  $V = E(L) + \sum Q_i$  on the horizontal axis. The ratio of the area under the response curve to the area of the triangle  $0AV$  is our primary measure of market efficiency. For a fully efficient industry, market efficiency would equal 1; and for an inefficient industry, market efficiency is between 1 and 0. We also consider other measures of industry performance, including the percentage of the total losses and the number of insolvencies.

### 3.2. Sample selection and modeling approach

The data for the study are taken from the regulatory annual statements filed by insurers with the National Association of Insurance Commissioners (NAIC). Our efficiency estimates are for 1997, the most recent report year available at the time the study was begun. To estimate parameters, we use data from the period, 1983–1997, providing fifteen annual observations on the companies in the sample.<sup>13</sup> We decided not to extend the sample prior to 1983 because the number of insurers for which we have complete time series would have been reduced significantly by including earlier years. Although companies present in the data base for 1997 but not for earlier years are included in our capacity estimation, the companies present in the sample for the entire sample period (the full-time series (FTS) companies) are important because they are used to estimate regression models to obtain the parameters of the companies that are not present for the entire sample period (see below). To obtain reliable parameter estimates, it is important to include as many companies as possible in the FTS regressions.

Two samples of insurers were selected – a national sample and a Florida sample – to represent the capacity of the industry to respond to national catastrophes and to Florida catastrophes, respectively. Use of the national

<sup>13</sup> Insurance prices and profits have been shown to be cyclical, with a cycle period between six and seven years (Cummins and Outreville, 1987). The fifteen year sample period thus gives us approximately two complete underwriting cycles.

sample assumes that the total reserves and equity capital of the industry are potentially available to pay catastrophic losses, while the use of the Florida sample assumes that the total resources of companies operating in Florida are potentially available to pay the costs of a Florida catastrophe. In both cases, the total resources of all insurers in the respective samples are assumed to be *potentially* available to pay catastrophic loss claims, even though some insurers do not write policies likely to be triggered by a catastrophe.<sup>14</sup> The fact that some insurers do not write insurance covering catastrophes, do not do business in catastrophe prone areas, or happen to be “lucky” in suffering relatively low losses as a result of a given event are captured by the estimated correlation coefficients  $\rho_i$  between company and industry losses. To the extent that differences in loss correlations under or over-adjust for these features of industry loss exposure and experience, our estimates must be viewed as approximations to the “true” industry capacity.

In selecting both the national and Florida samples, our objective was to maximize the number of companies that could meaningfully be included in the analysis. Thus, the screening criteria used in selecting the sample focused primarily on eliminating insurers that were not viable operating entities in 1997, such as firms that were experiencing severe financial difficulties or not actively participating in the market.<sup>15</sup> To be included in the Florida sample, insurers also were required to have positive losses in Florida in 1997.<sup>16</sup>

Ownership structure in the insurance industry also is likely to have an effect on market capacity. Many insurance firms are organized as *insurance groups*, consisting of several companies under common ownership. To allow for the potential impact of ownership structure on capacity, we conduct the analysis separately on the basis of two alternative assumptions about insurance groups. The first analysis is based on the assumption that the full resources of the group are available to support losses arising from any subsidiary of the group, i.e., the group is considered to act as a single firm. This is equivalent to assuming that groups *always* rescue failing subsidiaries. The second analysis ignores group affiliations entirely and conducts the analysis as if the members of groups are

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<sup>14</sup> For example, a company specializing in commercial liability insurance is not exposed to the property losses caused by a catastrophe and hence its resources would not be called upon to fund catastrophic loss claims.

<sup>15</sup> Insurers are required to report financial data to the NAIC even if they are undergoing severe financial difficulties, are inactive, or are in “runoff mode.” An insurer in runoff mode is engaged in settling existing claims but not writing or renewing policies currently. Such an insurer would not be “on the risk” for projected catastrophes.

<sup>16</sup> Losses rather than premiums were used for the Florida screen because an insurer can remain liable for loss payments in a given year even if it writes no premiums in that year because coverage is provided by policies written in the preceding year (and on which premiums had been paid in the preceding year) that had not yet expired at the beginning of the current year. The results would be nearly identical based on a premium screen.

freestanding, unaffiliated companies. This analysis implicitly assumes that groups *never* bail out failing subsidiaries. The two analyses can be viewed as giving upper and lower bounds on industry capacity.

The losses used in estimating capacity are net losses incurred, defined as direct losses incurred plus losses due to reinsurance assumed minus losses due to reinsurance ceded. Direct losses incurred are losses paid or owed directly to policyholders, while net losses incurred reflect the netting out of reinsurance transactions. Our analysis thus implicitly takes into account the effects of reinsurance on capacity.

### 3.3. Parameter estimation

To estimate capacity for the industry in 1997, we included in the sample all of the companies reported on by the NAIC in 1997 that met our screening criteria for operating viability. However, only a subset of these companies are in the NAIC data base for the full time period covered by the study (1983–1997). Accordingly, we adopt a three-stage procedure for estimating parameters.

In the first stage we estimate parameters for the companies that have data for the full time period 1983–1997. We refer to this set of companies as the FTS sample. Two sets of parameters are estimated – *raw* parameter estimates calculated directly from the FTS data, and *detrended* estimates based on the residuals from time trend regressions. The reason for computing the detrended estimators is that property–liability insurance losses are subject to a strong positive time trend. Thus, the raw estimates of the loss standard deviation capture trend-related growth in losses across years as volatility. However, the trend is highly predictable and insurers can easily plan for it by increasing premiums each year. Differences in losses across years due to this trend effect thus are not unanticipated loss fluctuations and probably should not be included when measuring the effect of catastrophes and other types of random shocks on insurance market capacity.<sup>17</sup> By measuring capacity using both the raw and detrended parameters, we avoid potential time-trend bias.

To define the raw and detrended parameters more precisely, let  $L_{it}$ , the observed losses of company  $i$  in year  $t$  and let  $L_t = \sum_i L_{it}$ , total industry losses in year  $t$ . The raw standard deviations are obtained using the following formulas:

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<sup>17</sup> It might be argued that insurers also could set aside reserves sufficient to pay for large catastrophic losses on the grounds that the probable maximum loss amounts due to catastrophes are reasonably predictable even though the time of these losses is unpredictable. However, as Jaffee and Russell (1997) point out, accumulation of large catastrophe reserves is not possible in practice due to legal, regulatory, accounting, and tax rules that constrain the ability of insurers to accumulate reserves for events that have not yet taken place.

$$\hat{\sigma}_i^2 = \frac{1}{T-1} \sum_{t=1}^T (L_{it} - \bar{L}_i)^2 \quad \text{and} \quad \hat{\sigma}^2 = \frac{1}{T-1} \sum_{t=1}^T (L_t - \bar{L})^2, \quad (10)$$

where  $\hat{\sigma}_i^2$ , the estimator of the variance of losses for company  $i$ ,  $\hat{\sigma}^2$ , the estimator of the variance of losses for the industry,  $\bar{L}_i = (1/T) \sum_t L_{it}$  and  $\bar{L} = (1/T) \sum_t L_t$ . The correlation coefficient between company  $i$ 's losses and the industry losses is estimated using the following formula:

$$\hat{\rho}_i = \frac{(\frac{1}{T-1}) \sum_{t=1}^T (L_{it} - \bar{L}_i)(L_t - \bar{L})}{\hat{\sigma}_i \hat{\sigma}}. \quad (11)$$

To obtain the detrended parameter estimates, we first conduct the following regressions:

$$\begin{aligned} L_{it} &= \alpha_{0i} + \alpha_{1i}t + \varepsilon_{it}, \\ L_t &= \alpha_0 + \alpha_1t + \varepsilon_t. \end{aligned} \quad (12)$$

Detrended estimates of  $\hat{\sigma}_i^2$  and  $\hat{\sigma}^2$  are obtained by applying the formulas in Eq. (10) to the estimated values of the residuals  $\varepsilon_{it}$  and  $\varepsilon_t$ , respectively, from Eq. (12); and the detrended estimate of  $\rho_i$  by applying Eq. (11) to the estimated residual series  $\varepsilon_{it}$  and  $\varepsilon_t$  from Eq. (12).

The final parameters to be estimated are the means,  $\mu_i$  and  $\mu_L$ . To estimate capacity for 1997, we set  $\mu_i$  and  $\mu_L$  equal, respectively, to company  $i$ 's and the total industry losses incurred for 1997. This implicitly assumes that the companies' net premiums are equal to incurred losses. Although this is not precisely correct, it is a good approximation, especially in view of the fact that there were no major catastrophes during the year.<sup>18</sup>

In the second stage of our parameter estimation procedure, we estimate regression models using the FTS sample with the estimated parameters as dependent variables and company financial characteristics as independent variables. The rationale for the regression analysis is twofold: First, the estimated parameter values for some insurers are likely to reflect non-recurring financial shocks leading to unusually high or low estimated parameters. Such parameters are likely to be non-representative of the actual parameters affecting these insurers in future periods. Using the fitted values of parameters from the regression models in place of the raw stage one parameter estimates enables us to smooth the parameter series by tempering the extreme observations. The second, and equally important, reason for conducting the regression

<sup>18</sup> As a robustness check, we also used fitted values from the regression time trend lines for 1997. The results were virtually the same using the actual and fitted losses to represent  $\mu_i$  and  $\mu_L$ .

analysis is that the regression models can be used to provide parameter estimates for firms that are not in the data base for a sufficiently long period to permit the reliable estimation of stage one parameter values. Parameters for these companies can be estimated by inserting their 1997 financial data into the regression models. Estimation of parameters for this set of companies (called non-full time series (NFTS) companies), by obtaining fitted values from the regression models, is the third stage in the parameter estimation process. Conducting the third stage enables us to include the maximum number of insurers in the sample and thus to obtain a comprehensive estimate of industry capacity.

#### 4. Empirical results

The estimation proceeds by calculating response functions using Eq. (9), separately for the national and the Florida samples. The response functions give the expected payout for each insurer as a function of its parameters, the industry parameters, and the total industry loss  $L$ . By varying  $L$ , we generate expected payments for each company for a range of industry losses, starting with a value of  $L$  approximately equal to industry expected losses and increasing to the point where  $L$  equals total industry resources. In addition to expected loss payments, the analysis also determines whether a company becomes insolvent (i.e., if its loss payment, conditional on  $L$ , exceeds its premiums and equity capital). For insolvent firms the total payment is capped at the sum of premiums and equity capital. Various statistics can be computed from the response function output, including industry efficiency, the percentage of total catastrophe losses paid, and the number of insolvencies.

As mentioned above, we conduct the estimation for two definitions of the industry in terms of the treatment of insurance groups. The first definition assumes that each insurance group acts as if it were a single firm. Based on this definition, the industry is defined as consisting of groups and unaffiliated single insurers. This industry definition is called the *group* sample. The second industry definition assumes that companies that are members of insurance groups operate independently. This industry definition is called the *company* sample.

##### 4.1. Summary statistics

Summary statistics on losses and equity capital, the two most important determinants of capacity, are shown in Table 1 for the Florida and national samples. The Florida figures are the countrywide totals of losses and equity for insurers doing business in Florida, rather than the Florida business of these companies, based on the rationale that the total resources of the company are

Table 1  
Summary statistics: losses and equity capital

Case	1997 Losses	1997 Equity	% of Total industry equity	Number of firms
National net loss: groups and unaffiliated cos	201,905.0	370,993.4	96.6%	1,248
National net loss: all companies	201,905.0	370,993.4	96.6%	2,256
Florida net loss: groups and unaffiliated cos	156,404.4	306,861.8	79.9%	431
Florida net loss: all companies	156,404.4	306,861.8	79.9%	898

*Note:* Losses and equity are in millions of dollars. Equity has not been adjusted for intra-group consolidations. An adjustment for consolidations was made in estimating capacity. Florida losses are the total (countrywide) losses of insurers operating in Florida.

available to pay losses from Florida catastrophes. The national sample captures 96.6% of industry equity, and thus provides an excellent representation of the industry as a whole. Companies doing business in Florida account for 79.9% of industry equity.

Average values of the raw and detrended parameter estimates are shown in Table 2. As expected, detrending significantly reduces the magnitudes of the loss standard deviations and the correlations between company and industry losses. Recall that the response functions are decreasing in the insurer's loss standard deviation and increasing in the correlation between the insurer loss and the industry loss. Because detrending leads to larger reductions in the correlations than in the standard deviations, we expect the estimated loss payments to be lower for the detrended parameter estimates than for the raw parameter estimates.

Table 2  
Detrended and raw parameter estimates: property-liability insurance industry

Case	Averages				
	Detrended sigma	Detrended correlation	Sigma	Correlation	<i>N</i>
National net loss: groups and unaffiliated cos	0.4112	0.1751	0.5188	0.4366	1,248
National net loss: all companies	0.4203	0.1916	0.5303	0.4320	2,256
Florida net loss: groups and unaffiliated cos	0.4110	0.1308	0.4760	0.4921	431
Florida net loss: all companies	0.4442	0.1821	0.5177	0.4683	898

The standard deviation estimates tend to be larger for the company sample than for the group sample, reflecting the smoothing effect of intragroup reinsurance transactions. The raw estimates of the correlation coefficients are somewhat larger for the group sample than for the company sample, as expected if intra-group reinsurance transactions tend to increase the covariability of the loss series. However, the detrended correlation coefficients and rho statistics are lower for the group sample than for all company sample, i.e., after removal of the time trend, there is less covariability among firms in the group sample than in the company sample.

*4.2. Industry capacity: The national sample*

The response functions for the national sample are shown in Fig. 2. The figure shows the estimated amounts that would be paid for industry losses ranging from \$200 billion to \$500 billion. These limits were chosen because total losses and loss adjustment expenses for the US property–liability insurance industry in 1997 were approximately \$200 billion and the total equity capital was approximately \$300 billion. Thus, the response curve ranges from the industry’s actual loss up to the industry’s total resources. Four response curves are shown in the figure, based on (a) raw parameters for the group sample, (b) detrended parameters for the group sample, (c) raw parameters for the company sample, and (d) detrended parameters for the company sample.

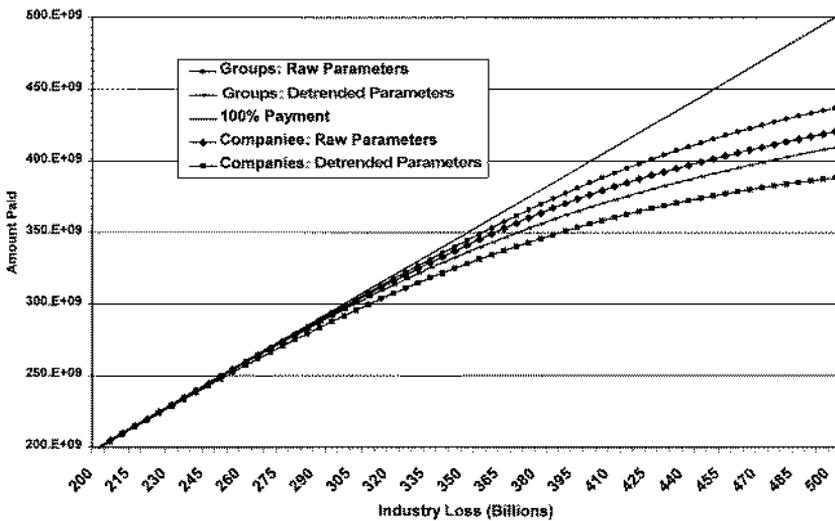


Fig. 2. Response functions: national net loss.

The estimated response curves are expected to follow certain ordering relationships, based on option pricing theory and the assumption regarding the exercise of the default option for failing insurers that are members of groups. Larger payments are expected when raw parameter estimates are used rather than detrended parameter estimates because removal of the time trend leads to a larger reduction in the correlation coefficients than in the standard deviations (see Table 2). Because the response function values are positively related to the correlation coefficient and negatively related to the standard deviation, the detrended parameters give lower estimated payments. Secondly, payments for the group sample are expected to be higher than payments using the company sample, holding constant the parameter set used in the estimation, i.e., for the raw parameter estimates, the estimated payments for the group sample should be larger than the payment for the company sample, and likewise for the detrended parameter estimates. In the group sample, if a company that is a group member exhausts its resources, payments continue to be made from the resources of other group members until the group's resources are exhausted. However, in the company sample, the failure of a company does not trigger additional payments from members of the same group, because group relationships are ignored in this estimation.

The expected relationships are borne out in the estimated response curves shown in Fig. 2. The largest estimated payments are obtained using the raw parameter estimates for groups, followed by the estimates based on the raw parameter estimates for companies, the detrended parameter estimates for groups, and the detrended parameter estimates for companies. Generally, a high proportion of total losses are paid for industry losses near to the expected value of \$200 billion and ranging up to about \$300 billion. Above that level, noticeable gaps begin to appear between the industry loss and the estimated payments.

The estimated efficiencies for the national sample are shown in Fig. 3. Recall that efficiency is defined as the ratio of the area below the curved lines in Fig. 2 to the total area represented by the triangle bordered by the 100% payment line and the horizontal axis. Obviously, the efficiencies will differ depending upon the value of industry loss used as the starting or attachment point. Accordingly, Fig. 3 shows efficiency for various attachment points ranging from \$200 to \$500 billion. Efficiency is inversely related to the attachment points. For an attachment point of \$200 billion, the efficiency estimates range from 91% based on raw parameters for the group sample to about 78% based on detrended parameter estimates for the company sample. For the highest attachment points, efficiencies range from about 80% based on raw parameters for the group sample to about 65% based on detrended parameters for the company sample.

The response function analysis also produces estimates of the percentage of losses that would be paid for catastrophes of different sizes (see Fig. 4). For

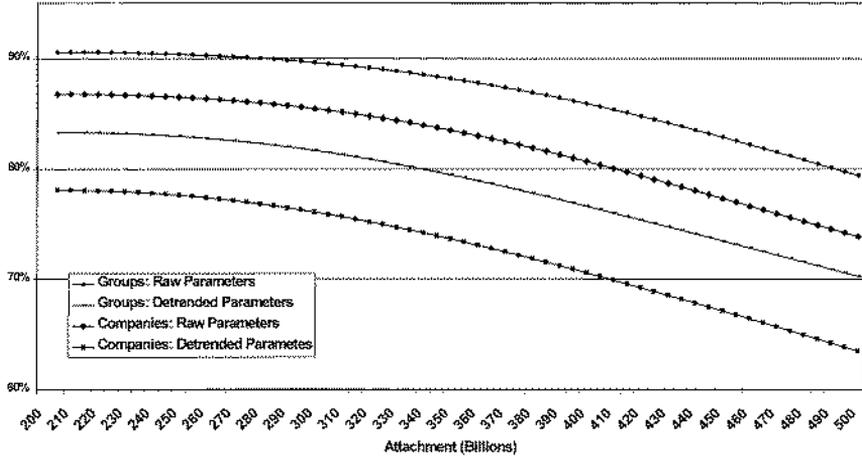


Fig. 3. Efficiency – national net loss.

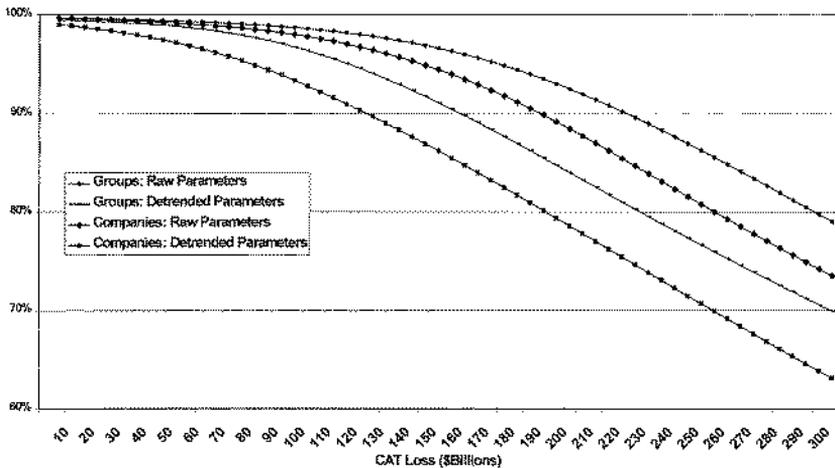


Fig. 4. Percent paid by CAT loss size – national net loss.

relatively small catastrophes, the industry would be able to pay very high percentages of the loss. For example, for a \$20 billion catastrophe, we estimate that the industry could pay at least 98.6% of the loss. The estimated percentages paid for larger losses decline at an increasing rate. For example, using the detrended parameter estimates, the industry would be able to pay about 96.4% of a \$100 billions loss based on the group sample and 92.8% based on the company sample. For a \$200 billion loss, the industry could pay 84.0% based on the group sample and 78.6% based on the company sample.

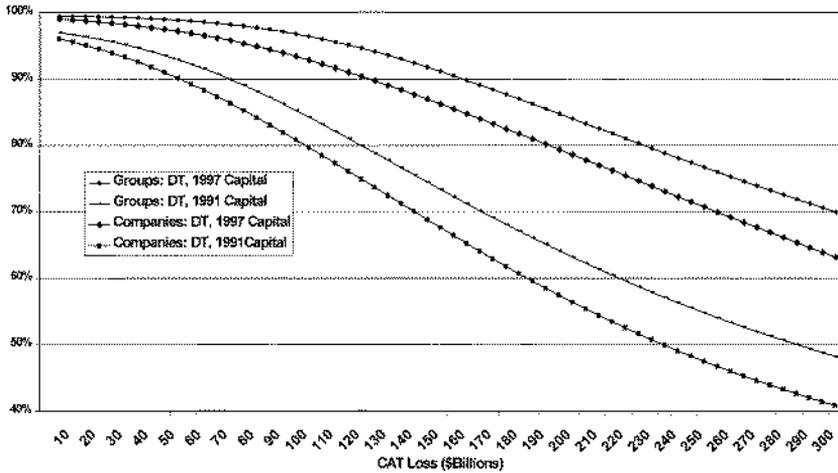


Fig. 5. Percent paid by CAT loss size – national net loss 1991 versus 1997 capitalization.

The significant capacity of the industry to respond to catastrophes in the range of losses represented by Hurricane Andrew and the Northridge earthquake is primarily due to an increase in the relative capitalization of the industry over the past few years. The ratio of premiums to surplus, a commonly used leverage ratio in the insurance industry, was 1.4 in 1991, prior to Andrew, but had declined to 0.9 in 1997.<sup>19</sup>

We conduct an additional analysis to determine the impact on capacity of the increase in capitalization since 1991. A gauge of the capitalization increase that is more consistent with our model than the premiums to surplus ratio is the ratio of capital to losses. In 1991, the ratio of capital to losses was \$0.88, while in 1997 the ratio was \$1.56. We recalculated the 1997 capacity of the industry after reducing capital proportionately for the firms included in our sample so that the ratio of 1997 capital to losses was the same as in 1991, i.e., \$0.88. The results are presented in Fig. 5, which plots the expected company and group payments for catastrophes of various sizes, based on 1991 and 1997 capitalization. To reduce the number of curves on the chart and focus on the most realistic results, Fig. 5 includes only the capacity estimates based on detrended parameter values.

Fig. 5 reveals a noticeable increase in industry capacity to bear catastrophic losses between 1991 and 1997. Focusing on the detrended company loss esti-

<sup>19</sup> The increase in capitalization reflects the strong investment performance of the 1990s, capital inflows due to concern about catastrophe risk, and the introduction of risk-based capital (RBC) regulation in 1995. See Cummins and Nini (2001).

mates, for a \$20 billion catastrophe, the industry would be able to pay 98.6% on 1997 capitalization levels, compared to 94.5% based on 1991 capitalization levels. The results are even more dramatic for larger catastrophes. For a \$100 billion catastrophe, again based on detrended company parameters, the industry could pay 92.8% based on 1997 capitalization but only 79.6% based on 1991 capitalization. For a \$200 billion catastrophe, the industry could pay 78.6% based on 1997 capitalization but only 56.4% based on 1991 capitalization. The capacity of the industry, even for catastrophes in the \$100 billion range, is clearly much larger in 1997 than it was prior to Andrew and Northridge. However, even at 1997 capitalization levels, a \$100 billion catastrophe would disrupt the market by causing a significant number of insolvencies. For example, based on the detrended parameters, a \$100 billion catastrophe is projected to cause 30 insolvencies for the group sample and 136 insolvencies for the company sample. The comparable numbers of insolvencies at 1991 capitalization levels would be 108 groups and 216 companies.

#### 4.3. Industry capacity: The Florida sample

We estimated response functions and efficiencies for the Florida market. Though we do not show these results here we note that, because the number of insurers operating in Florida is smaller than the number operating nationally, the resources available to pay claims in Florida is commensurately reduced and this reduces efficiency. For example, at an attachment point of \$200 billion, the Florida efficiency based on raw parameter estimates for the group sample is about 85%, compared to 91% at the same attachment point for the national case. Based on detrended parameter estimates for the company sample, the efficiency at the \$200 billion attachment point is 72% in Florida, compared to 78% nationally.

The estimated Florida payments for catastrophic losses of various sizes are shown in Fig. 6 for the detrended parameter estimates at 1997 and 1991 capital levels. As in the national case, industry capacity to respond to moderate catastrophes appears to be adequate both in 1997 and 1991. For a catastrophe of \$20 billion, the expected payment for the group sample at 1997 capital levels is 99.4%, compared to 97.9% at 1991 capitalization. The comparable figures for companies are 98.6% and 94.4%, respectively. Capacity in 1997 also appears to be reasonably adequate for a catastrophe of \$100 billion. The expected payment for groups would be 94.2% and the payment for companies would be 89.7%. At 1991 capitalization levels, on the other hand, the capacity of the industry to finance a \$100 billion catastrophe was much lower – 77.5% payment by groups and only 72.2% by companies. The principal finding is that the capacity of the industry increased dramatically between 1991 and 1997 and now is adequate to bear catastrophes in the range of the projected “Big One” (e.g., \$100 billion). However, such a catastrophe would still be disruptive to the

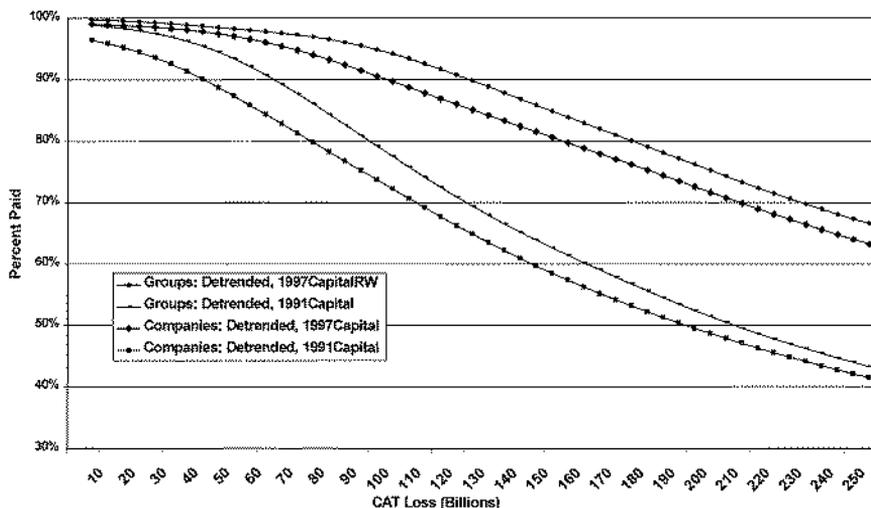


Fig. 6. Percent paid by CAT loss size – Florida net loss 1991 versus 1997 capitalization.

insurance market because it is projected to cause the failure of 34 companies and 10 groups.

#### 4.4. Regression models for parameter estimation

Finally, we provide examples of the regression models used in estimating the parameters for the companies in the market in 1997 that did not have data for the full time period covered by the study (the NFTS companies). The procedure is to estimate regression models with the parameters of the FTS companies as dependent variables and company financial characteristics as regressors. The NFTS company parameters are estimated by inserting the financial characteristics of these firms into the equation to obtain fitted parameter values, which are used in estimating capacity.

The regression models are based on the underlying theoretical principle that insurers seek to maximize returns for a given level of risk (see Cummins and Sommer, 1996). There are two primary reasons why insurers are likely to have target risk levels: (1) The primary creditors of financial firms are also their customers (Merton and Perold, 1993), e.g., the primary debt capital of property–liability insurers consists of policy reserves, which constitute funds held to pay policyholder claims. Because the purpose of insurance is likely to be subverted if the debt claims are overly risky, insurers incur a product market penalty for taking excessive risk (Cummins and Danzon, 1997), providing an important rationale for having a risk target. (2) Insurers are subject to rigorous solvency regulation that includes RBC requirements. The RBC rules subject

Table 3  
Regression models of raw standard deviations: Net losses incurred

Variable	Florida companies	National companies	Florida groups	National groups
Intercept	1.825 8.047	1.328 9.588	1.297 5.253	0.970 5.367
Equity capital/assets	-0.817 -5.502	-0.800 -8.358	-0.761 -3.320	-0.540 -3.423
Ln(net losses incurred)	-0.296 -10.126	-0.357 -20.645	0.338 -6.219	-0.355 -12.040
Ln(equity capital)	0.221 7.124	0.309 17.223	0.293 5.333	0.317 10.467
Return on assets	0.930 2.358	1.852 6.270	1.339 1.155	3.966 7.509
Net income/net premiums written	0.194 1.711	-0.183 -3.730	-0.564 -2.499	-0.545 -5.405
Reinsurance accounts receivable/assets	1.133 3.417	0.722 3.258	1.698 3.335	0.770 2.008
Stocks/assets	-0.036 -0.313	-0.194 -2.629	-0.012 -0.075	-0.269 -2.222
Adjusted $R^2$	37.9%	40.1%	33.1%	44.6%
No. of observations	511	953	172	286

Note: The dependent variable is the standard deviation of losses over the period 1983–1997. For each variable, the upper number is the regression coefficient and the lower number is the  $t$ -ratio.

insurers to increasingly restrictive regulations if capital declines below specified thresholds, imposing potential regulatory costs on insurers that can be avoided by holding capital sufficiently in excess of the RBC thresholds (Cummins et al., 1994). The existence of target solvency levels would imply that firms which are relatively risky along one dimension, such as investment risk, are likely to compensate by reducing risk along other dimensions. We report the results of these regressions in Table 3. Though we will not discuss these results here, we will simply mention that they are roughly consistent with the solvency target theory.

## 5. Conclusions

In this article, we conduct a theoretical and empirical analysis of the capacity of the US property–liability insurance industry to finance major catastrophic property losses. In our theoretical analysis, we show that the necessary condition for industry capacity to be maximized is that all insurers hold a proportionate share of the industry underwriting portfolio. The sufficient condition for capacity maximization, given a level of total resources in the industry, is for all insurers to hold a net of reinsurance underwriting portfolio which is perfectly correlated with aggregate industry losses. Based on these

results, we derive an option-like model of insurer responses to catastrophes, where the total payout, conditional on total industry losses, is a function of the industry and company expected losses and standard deviations of losses, company net worth, and the correlation between industry and company losses. The industry response function is obtained by summing the company response functions, providing an estimate of industry capacity.

The empirical analysis estimates the capacity of the industry to bear losses ranging from the expected value of loss up to a loss equal to total industry resources. We develop a measure of industry *efficiency* equal to the ratio of the estimated loss payment based on our model to the loss that would be paid if the industry acts as a single firm. For example, using detrended group parameter estimates, the results indicate that national industry efficiency ranges from about 83.3% to 81.6%, based on catastrophe losses ranging from zero to \$300 billion, and from 76.6% to 70.2%, based on catastrophe losses ranging from \$200 to \$100 billion. The industry has more than adequate capacity to pay for catastrophes of moderate size. For example, based on both the national and Florida samples, the industry could pay at least 98.6% of a \$20 billion catastrophe at 1997 capitalization levels. For a catastrophe of \$100 billion, the industry could pay at least 92.8% nationally and at least 89.7% in Florida.

We also compare the industry's capacity to respond to catastrophic losses based on 1997 capitalization with its capacity based on 1991 capitalization, motivated by the sharp increase in capital following Hurricane Andrew and the Northridge earthquake. In 1991, the industry had \$0.88 in equity capital per dollar of incurred losses, whereas in 1997 this ratio had increased to \$1.56. To compare 1991 and 1997, we proportionately reduce the capital of the insurers in our sample to achieve an industry-wide capital-to-loss ratio of \$0.88 in 1997. Our lower bound estimates of nationwide industry capacity suggest that the industry could have paid 92.8% of a \$100 billion catastrophe loss in 1997 but only 79.6% in 1991. For the Florida sample, insurers could have paid at least 89.7% of a \$100 billion catastrophe in 1997 but only 72.2% in 1991. Thus, the ability of the industry to pay for "The Big One" increased dramatically between 1991 and 1997.

## References

- Borch, K., 1962. Equilibrium in a reinsurance market. *Econometrica* 30, 424–444.
- Cummins, J.D., Nini, G., 2001. Optimal capital utilization by financial firms: Evidence from the property-liability insurance industry. *Journal of Financial Services Research*, forthcoming.
- Cummins, J.D., Danzon, P., 1997. Price shocks and capital flows in liability insurance. *Journal of Financial Intermediation* 6, 3–38.
- Cummins, J.D., Outreville, F., 1987. An international analysis of underwriting cycles. *Journal of Risk and Insurance* 54, 246–262.

- Cummins, J.D., Sommer, D., 1996. Capital and risk in property–liability insurance markets. *Journal of Banking and Finance* 20, 1069–1092.
- Cummins, J.D., Weiss, M.A., 2000. The global market for reinsurance: Consolidation, capacity, and efficiency. *The Brookings-Wharton Papers on Financial Services*, pp. 159–222.
- Cummins, J.D., Harrington, S.E., Niehaus, G., 1994. Risk-based capital requirements for property-liability insurers: A financial analysis, 1994. In: Altman, E., Vanderhoof, I. (Eds.), *The Financial Dynamics of the Insurance Industry*. Irwin Professional Publishers, Homewood, IL.
- Cummins, J.D., Lewis, C.M., Phillips, R.D., 1999. Pricing excess of loss reinsurance contracts against catastrophic loss. In: Froot, K. (Ed.), *The Financing of Catastrophe Risk*. The University of Chicago Press, Chicago.
- Doherty, N.A., Tinic, S., 1981. A note on reinsurance under conditions of capital market equilibrium. *Journal of Finance* 36, 949–953.
- Froot, K.A., O’Connell, P.J.G., 1996. The pricing of U.S. catastrophe reinsurance. In: Froot, K. (Ed.), *The Financing of Catastrophe Risk*. The University of Chicago Press, Chicago.
- Guy Carpenter, 1998. 1998 review: United States property catastrophe programs. *Guy Carpenter’s Monitor*, New York.
- Jaffee, D.M., Russell, T., 1997. Catastrophe insurance, capital markets, and uninsurable risks. *Journal of Risk and Insurance* 64, 205–230.
- Lewis, C.M., Murdock, K.C., 1996. The role of government contracts in discretionary reinsurance markets for natural disasters. *Journal of Risk and Insurance* 63, 567–597.
- Merton, R., Perold, A., 1993. The theory of risk capital in financial firms. *Journal of Applied Corporate Finance* 6, 16–32.
- Myers, S.C., 1977. Determinants of corporate borrowing. *Journal of Financial Economics* 5, 147–175.
- Swiss Re, 1997. Too little reinsurance of natural disasters in many markets. *Sigma* 7, 3–22.
- Swiss Re, 2000. Natural catastrophes and man-made disasters in 1999: Storms and earthquakes lead to the second-highest losses in insurance history. *Sigma* 2, 33–34.