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THE MARKET FOR CATASTROPHE RISK: A CLINICAL EXAMINATION

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ABSTRACT

This paper examines the market for catastrophe event risk -- i.e., financial claims that are linked to losses associated with natural hazards, such as hurricanes and earthquakes. This market is in transition as new approaches for transferring risk are being explored. The paper studies several recent transactions by USAA which use reinsurance capacity from capital markets, rather than only from reinsurers. We identify two puzzles concerning the cat protection purchased in these transactions: there is no coverage for the largest, most severe events; and premiums appear well above actuarial value. We demonstrate that both features deviate from what theory would predict, yet are characteristic of many transactions, not simply those of USAA. We then explore a number of possible explanations for the facts. The most compelling are combinations of capital market imperfections and market power on the part of reinsurers. Conclusions for broader capital market and risk management issues are discussed.

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1. Introduction

Hurricanes, earthquakes, wind and ice storms, floods, etc. have long been known to cause large and unexpected losses among owners of physical capital. Recently, it has become more widely appreciated that a single hurricane or earthquake could result in damages of well over $50 billion. Given the growth rates in physical asset values and in population in high-risk zones, distribution of catastrophe event losses continues to grow.

Because households are risk averse, they have a strong incentive to share their risks with others through the purchase of insurance. Corporations – to the extent they have a well-foundered concern with risk management – also have an incentive to purchase insurance and reinsurance. If these groups behave in a risk averse manner, then they treat severe losses as expectationally more costly than moderate losses. Thus, one would expect insurance and reinsurance to focus on catastrophic outcomes. Moreover, since cat event losses are uncorrelated with (and perhaps even independent of) financial wealth, the premiums for such catastrophic protection should, if markets are perfect, be close to expected losses.

This paper explores these propositions and the market for cat event risk by examining in depth several recent reinsurance transactions completed for USAA, one of the largest insurance companies in the US. These transactions have been widely discussed. They are among the first to back reinsurance with dedicated collateral supplied by bondholders – otherwise known as cat bonds. Traditionally, reinsurance has been backed by the general credit of reinsurers, who use equity to fund a portfolio of reinsurance liabilities. We demonstrate that these transactions display the two characteristics above: that very large losses are not covered; and that premiums are very large compared with expected losses.

We then attempt to analyze these transaction features in two ways. First, we attempt to show that they do indeed conflict with what equilibrium models would predict about the profile and price of reinsurance coverage. Second, we provide evidence from a large sample of reinsurance transactions, in order to put the clinical data points in perspective. The large-sample evidence demonstrates that the USAA coverage has had very much in common with other, traditional reinsurance transactions.

The paper then turns to why this is the case: what could explain the widespread tendency to underinsure (particularly for large events) and to set prices so high. We look at eight different explanations. The majority of these focus on distortions on the supply side, but several suggest problems with the demand side as well. The most important explanations are supply-side stories of capital market imperfections facing reinsurers and the exercise of market power by reinsurers.

The most interesting implications of the evidence we present go well beyond the cat risk market itself. After all, cat risk will never be a very large standalone asset class. In the conclusions, we discuss several lessons drawn from this evidence for the broader behavior of capital markets and corporate risk management.

2. Recent Reinsurance Contracts: Clinical Evidence

2.1. USAA: The company

To understand the developments in the traditional reinsurance market and the associated risk transfer mechanisms, it is useful to investigate USAA's recent purchases of reinsurance. USAA is the fifth largest private passenger automobile insurer and the fourth largest homeowner insurer in the United States. It sells exclusively to U.S. military officers and their families and is organized as a mutual insurance company. Because of its military customer base, USAA has relatively little control over the geographic pattern of its exposures that come disproportionately from California and Florida.

The risk of Florida hurricane is a real one for USAA. In August 1992, Hurricane Andrew swept through Florida and Louisiana, causing losses of $620 million to USAA and approximately $17.9 billion to the insurance industry overall, of which 67% was residential.[2,3] Hurricane Andrew was by far the most costly insured cat event in the US over the last 30 years, even when all loss figures are expressed in constant dollars. Small changes in Andrew's trajectory would have resulted in major changes in total industry and USAA losses.

2.1.2. USAA's 1997 reinsurance program

In many respects, USAA's catastrophe reinsurance program looked like the programs of other insurers. USAA purchased reinsurance in "excess-of-loss layers" conforming to different cat-triggered loss amounts.[4] The main parameters of an excess-of-loss layer are the "retention," "limit," "exceedence" and "exhaustion" probabilities, and amount of "coinsurance." The retention is just the deductible – the level that losses must exceed before coverage is triggered. The probability that losses reach this level is the exceedence probability. The contract limit is the maximum recovery that can be made. The probability of reaching a loss that exhausts the limit is the exhaustion probability.

Most reinsurance contracts require that the cedent share, or coinsure, a portion of the layer – usually between 5% and 20%. Coinsurance and positive retention levels help diminish moral hazard and adverse selection. Essentially, reinsurance layers are call spreads written on a company's underlying cat losses: long one call struck at the retention or exceedence point, short one call struck at the retention plus limit, or exhaustion point. The risk period for these contracts is typically one year.

USAA began contemplating alternatives to traditional reinsurance beginning in 1993. By mid-1995, proposals had been requested from bankers on securitized risk transfer ideas.

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[2] Source: John Major, "A Synthetic History of the Guy Carpenter Catastrophe Index," Guy Carpenter, 1997.

[3] Dollar amounts in the text are in 1996 dollars unless stated otherwise.

[4] Only paid claims associated with event-triggered losses are reimbursable under standard cat reinsurance contracts.

By early 1996 USAA had selected three investment banks for the execution of a cat bond transaction for the hurricane season beginning in July 1996. However, even though the bankers had 4 or 5 months to construct the transaction, it could not be completed that year. Among the most important reasons were that: few investors understood the securities; rating agencies had no established criteria on which to rate cat bonds; regulators had to agree that Residential Re's noteholders were not, in fact, writing insurance (something that they generally were not licensed to do); and legal, regulatory and tax complications made finding the right location for the special purpose vehicle complicated. Because of these problems, the issue did not come to market until mid-1997 for the risk period running from June 1997 to June 1998.

Figure 1 and Table 1 provide a simple depiction of the layers of USAA's 1997 reinsurance program. In prior years, USAA had purchased reinsurance to cover losses up to $1 billion only. In 1997 the company decided to extend its coverage up to losses of $1.5 billion. It hoped to source this capacity directly from the capital markets. The reasoning for doing so, according to Steve Goldberg, the chief architect of USAA's capital market's effort, was that "traditional reinsurance capacity is necessarily limited..." and that "what was needed for USAA as well as other intermediaries was a long term "supplement of additional capacity."[5]

2.1.3. Residential Re

As Figure 1 shows, the top-most layer was reinsured through the capital markets using an independent, special purpose reinsurer called Residential Re. Residential Re's sole purpose was to be an efficient provider of reinsurance to USAA; it would do no other business. For tax and regulatory reasons, the company needed to be run entirely independently of USAA. Residential Re provided a one-year reinsurance contract to USAA, covering events which struck between the dates of June 16, 1997 and June 14, 1998. (See Figure 2 for a time-line.)

From USAA's perspective, the reinsurance contract written by Residential Re differed in several respects from those commonly written by reinsurers. The first difference was that the contract covered a single event only – USAA would have the right to choose one and only one event from the risk period. Typically, reinsurance contracts covered losses for any number of events that breached the retention, until the limit was exhausted.[6] The second difference concerned credit risk. Residential Re's sole purpose was to write a single reinsurance contract for USAA. It would dedicate collateral equal to the contract limit. As a result, there was virtually no chance of default once a claim against the contract was made. Traditional reinsurers did not fully collateralize individual contract limits, and therefore could conceivably default on their obligations in sufficiently dire states of nature.[7]

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[5] See Goldberg (1997).

[6] Traditional reinsurance contracts often contain a reinstatement provision specifying that a new premium is to be paid to extend additional coverage after the initial limit is exhausted. Often the reinstatement would be mandatory. The Residential Re contract, however, had no reinstatement provisions.

[7] For additional details on the Residential Re contract, See Froot and Seasholes (1997).

Residential Re agreed to reimburse 80% of USAA's single-event cat losses between $1 billion and $1.5 billion, making the reinsurance contract limit $400 million (0.8 x ($1.5 billion - $1.0 billion)). To collateralize this limit, Residential Re sold A-1 and A-2 notes. The A-2 notes, totaling $313 million, had all of their principal at risk. Thus, if an event resulted in USAA losses exceeding $1.5 billion, USAA would receive $313 million from A-2 noteholders' principal.

The A-1 notes were slightly more complicated, as they blended part of an A-2 note with a Treasury strip. This latter feature provided the A-1s with principal protection. Specifically, $164 million in A-1 notes were sold. The A-1 principal was then divided in two parts. The first part was $87 million, which effectively went toward the purchase of A-2 notes. The remaining $77 million went toward the purchase of 10-year US Treasury strips with a maturity value of $164 million if an event occurred. The strips allowed A-1 holders to receive full principal repayment regardless of what happened. This meant that the first $87 million would sustain losses pari passu with the A-2 notes. Thus, between the A-1s and A-2s, reinsurance collateral of $87 million + $313 million = $400 million was available from Residential Re to pay USAA's admissible event losses.

In order to have time to process insurance claims for disaster victims and therefore to determine the extent of USAA losses, Residential Re notes featured a six-month extended claims period. If no event occurred, the due date of the notes was June 14, 1998 – a 1 year maturity. If an event did occur, however, USAA could elect to extend the notes' maturity until December 15, 1998. During this time, USAA was to pay Residential Re an additional half year's premium. The reinsurance contract, however, was not similarly extended. Thus, if USAA elected to extend the notes, it would pay 1.5 years premium for 1 year of risk protection.

In return for the reinsurance, USAA agreed to pay Residential Re $24 million, or 6.0% of the limit.[8] After fees, noteholders received LIBOR plus 576 basis points for putting funds at risk. Thus, A-2 and A-1 holders received fractions (313/400 and 87/400, respectively) of the premium based on capital at risk. For every dollar noteholders put at risk of a one-year cat-event loss, they took out 5.76 cents in guaranteed premium.

2.1.4. Actuarial probabilities

The risk of loss to the reinsurance contract was modeled by Applied Insurance Research, Inc. (AIR), one of several independent firms specializing in the probabilistic modeling of catastrophic events. AIR (along with its main competitors, EQECAT and Risk Management Solutions) model the climatology of atmospheric disturbances, the geophysics of earthquakes, and the engineering of building structures, etc. They hire actuaries, engineers, geophysicists, software specialists, and mathematicians. Using Monte Carlo methods, AIR developed a probability distribution of losses for USAA's specific portfolio on insured homes and autos, shown in Figure 3 below. AIR estimated that the Residential Re layer had a 97 basis point probability of exceedence and a 39 basis

[8] This excludes fees to USAA of approximately 100 basis points.

point probability of exhaustion. The *expected* loss for the layer (i.e., the integral of the probability of a given loss times the associated loss of principal) was estimated to be 63 basis points.

These actuarial estimates of expected loss stand in striking contrast to the size of the premium. In equilibrium we would expect a zero-beta risk to have an *expected* return equal to the riskfree rate. This implies that the theoretical spread over LIBOR for the cat-event risk in the Residential Re layer is 63 basis points.[9] In return for putting capital at risk, investors received 576 / 63 = 9.1 times the actuarially fair premium!

When the issue came to market, it attracted considerable interest. The notes were approximately 3 times oversubscribed. In the days following the issue, the yield fell from 576 basis points to the mid-400s, suggesting that there was indeed excess demand.

It also appeared that investors were not the only ones interested in providing this reinsurance capacity. There were unconfirmed rumors that a major cat reinsurer had attempted to undercut the bond offering by promising to write the full reinsurance contract for a lower premium, without the additional expenses or complications created by these bonds.[10]

2.2. CEA 1996

Such undercutting by a traditional reinsurer of a proposed cat bond offering had happened before. In 1996 the State of California had decided to assemble a fund – the California Earthquake Authority (CEA) – to help insurance companies finance potential earthquake losses. In November 1996 the CEA announced that it had decided to purchase reinsurance from National Indemnity, a subsidiary of Berkshire Hathaway. National Indemnity is one of the world's largest reinsurers and easily the biggest single reinsurer of "super-cats" (high incidence, low probability cat layers).

A purchase of traditional reinsurance was, however, not the expected outcome. Over the prior year, California's insurance commissioner had solicited detailed proposals from investment banks for a CEA cat bond. During the year the commissioner had chosen a lead bank for the bond's issuance. This proposed CEA offering was similar to the USAA transaction, though it was more than double its size. A CEA bond would have attracted considerable attention as a watershed transaction. However, it was not to be. Just as the investment bank's underwriting mandate was to be signed, National Indemnity intervened, offering a lower premium than the bond would have required.[11] The offer

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[9] Of course, LIBOR itself is not risk free and on average exceeds the US Treasury bill rate by on average 40bp. There is, however, also some amount of credit risk associated with the special purpose vehicle. Assuming that this credit risk charge is lower than that applied to major money-center banks, all our computations are conservative by using LIBOR as the corresponding "risk-free" benchmark.

[10] Based on a private communication with Christopher McGhee, Managing Director, Marsh McLennan Securities Corp.

[11] The bonds would have incurred considerable incremental legal and modeling expenses as well as transactional uncertainty due to the unprecedented nature of the transaction. This latter feature, in

was particularly unusual given that the limit exceeded $1 billion, well in excess of the limit a typical reinsurer would assume in a single transaction.

Why did National Indemnity attempt to undercut this transaction? Under the structure of CEA's four-year reinsurance contract with National Indemnity the actuarially expected loss was 1.7% and the limit $1.05 billion. In return for bearing the earthquake risk, National Indemnity would receive an annual premium of $113 million – or 6.3 times actuarially expected losses of $1.8 million.[12] In fact, the terms were slightly better, as the contract called for Berkshire Hathaway to receive all four annual premiums in the first two years. Since the $1.05 billion limit aggregates over the 4 year period, the gamble effectively amounted to Berkshire putting up about $600 million in downside exposure for a 93.4% chance to make about $400 million in premium.[13]

Berkshire Hathaway shareholders seemed to agree that the CEA contract was a windfall for their firm. The contract announcement appears to have increased Berkshire's stock market valuation by almost $300 million, or 75 basis points in excess of the broad stock market change.[14] Figure 4 demonstrates. This suggests that shareholders saw the CEA reinsurance contract (and those that might follow) as being priced well above "fair" value.

While information on Berkshire Hathaway's bidding tactics is understandably sketchy, market participants acknowledge repeated interventions by the firm in undercutting potential capital market transactions. As a very recent example, rumors are that, in early July 1999, Berkshire Hathaway again underbid a potential $250 million cat bond issue, by XL, a major Bermudan reinsurer. The bond issue was quite far along, but Berkshire Hathaway made an eleventh-hour offer to provide all of the capacity in return for a premium that was below the total cat bond costs to XL.[15]

These tactics are now strongly associated with Berkshire Hathaway, and they have fueled speculation among reinsurance specialists that Buffett attempted, but failed, to undercut the 1997 Residential Re offering as well. Indeed, Buffett's annual letter to Berkshire Hathaway shareholders has done little to dampen this speculation. In several of these letters around the time of the offering, he alludes to the size of Berkshire's balance sheet

particular, may have influenced CEA's decision, given the insurance commissioner's status as a publicly elected official.

12 The average annual premium for the 4 year aggregate cover was 10.75% of the annual limit, whereas the likelihood that the reinsurance is triggered was 1.7%, according to EQE International, a catastrophe risk modeling firm. This yields 10.75 / 1.7 = 6.3 premium times expected loss.

13 Based on a probability of 1.7% per year, the chance of no event over the four years is $(98.3\%)^4 = 93.4\%$. Data in this paragraph are from *IBNR Insurance Weekly* (Volume III, #46), Dowling & Partners Securities, LLC.

14 The contract announcement by Berkshire Hathaway occurred on Friday 11/15/96, after market close. On Monday, 11/18/96, Berkshire's class A shares closed at $33,200, up from Friday's close of $33,000 (total equivalent class A shares outstanding were 1,210,762). Over the same period, the S&P 500 fell from 737.62 to 737.02.

15 Private communications with reinsurance brokers and investment bankers from Guy Carpenter, Goldman Sachs, and Marsh McLennan Securities. Thanks to Christopher McGhee for bringing this to my attention.

as being an important competitive advantage in reinsurance, allowing it to "move quickly to seize investment opportunities."

2.3. Residential Re 1998 and 1999

In 1998 and 1999, Residential Re purchased reinsurance contracts from incarnations of Residential Re that were nearly identical. The terms of the reinsurance have evolved slightly over time, with important differences summarized in Table 2. All of the 1998 and 1999 notes were like the 1997 A-2s, in that all principal was at risk. There was therefore no need for a Treasury strip or defeasance mechanism in the 1998 or 1999 programs. The exposures covered by the policy were essentially the same, as USAA's underwriting profile changed only marginally during this time.

Perhaps the most important difference in the notes was the premium received by investors. It fell from 5.76% in 1997 to 4.12% in 1998 and to 3.66% in 1999. Although not as well publicized, there was a decline in expected loss as well. As Table 2 shows, the expected loss rate stood at 63 basis points in 1997; this fell to 52 basis points in 1998 and 44 basis points in 1999. Because expected losses declined, the ratio of premium to expected loss fell by less than premiums – from 9.1 in 1997 to 7.7 in 1998 and 8.3 in 1999.

The decline in expected loss appears surprising at the outset. During this period, property values and construction prices rose somewhat, and there was a slight increase in the number of units USAA insured. Thus, based on exposures alone, there was an increase of approximately 5% in the expected loss for a 1%-likely event from 1997 to 1999. The main reason for the decline was therefore not a change in exposure, but a set of incremental changes made to the AIR model. The overall effect of these is shown in Table 3. Changes were made in the way the model generates events, event paths, and geographic windfield speeds. Changes were also made in the way the model estimates damageability from high winds and storm surge, and estimates the demand surge (i.e., the additional costs due to relative scarcity of contractors, materials, etc. in the aftermath of a storm). These changes were important in that use of the 1997 AIR model for all years would show an *increase* (rather than a decrease) in exposure and expected loss.[16]

It is also interesting to note that the 1999 Residential Re contract limit is smaller – $200 million versus $400 million and $450 million for the 1997 and 1998 programs, respectively. For the 1999 renewal, USAA is supplementing the Residential Re contract by purchasing a nearly identical reinsurance contract for $250 million from traditional reinsurers. Thus, between these two contracts USAA will in 1999 again be covering $450 million (i.e., 90%) of its single-event losses between $1.0 billion and $1.5 billion.

It is likely that USAA has bifurcated its 1999 coverage for several reasons. First, by splitting the program, USAA may succeed in stimulating greater competition between the

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[16] See Residential Reinsurance (1999) for more details. It is unclear which version of the model should be used to evaluate each year's expected losses. We apply the version of the model that was current for each year of the program. This assumes that the market thought the expectation of future revisions was zero.

traditional reinsurance and cat securitization markets. Overall program costs would therefore fall further by instituting such a split. Given the extent to which premiums for traditional reinsurance have fallen over time (see the discussion below), there is a concern that capital markets premiums would not otherwise decline as quickly.

There is some evidence to support the competition argument. The premium paid by USAA for the $200 million 1999 Residential Re program was 3.66% received by investors, plus 0.21% for a swap to deliver LIBOR and for minor day-count adjustments (excluding fees). At the same time, USAA locked in a nearly-equal premium rate on the $250 million traditional reinsurance portion of the 1999 program. This experience differed from that of earlier years. In both 1997 and 1998, it was rumored that USAA paid more for the Residential Re program than it would have for traditional reinsurance. (Note this comparison does not take into account the differences in credit quality between a collateralized special purpose vehicle and a standard reinsurance company, nor does it take into account the additional fees required for the bond-financed program.) While paying more may have been justified as an investment in developing the capacity of the capital markets, the returns on further investments of this kind are likely to be low.

Second, while the 1997 and 1998 Residential Re notes were oversubscribed, there was some concern about whether the same would be true in 1999. Large portions of the 1997 and 1998 programs were purchased by 2 large institutions. One of those dropped out in 1998, but the other, a single large hedge fund, reportedly increased its purchase substantially that year. However, this hedge fund experienced severe financial difficulties in the late summer and fall of 1998 and was unlikely to participate in 1999. These developments, coupled with the lower reinsurance market premiums, may have led to concerns about the success of a full $450 million issue of 1999 Residential Re notes.

3. Puzzles

The USAA transactions discussed above raise two basic puzzles for financial economists:

1) What explains USAA's purchase profile of reinsurance, with it buying protection for relatively minor cats while remaining exposed for large cats?

2) Why do USAA's premiums appear to be so high?

We try to explain these puzzles in Section 3 below. However, before doing so, it is useful first to gain some perspective. To do so we attempt to show that these features of USAA's reinsurance are representative of the broader cat risk market.

3.1. The profile of reinsurance purchases

The first puzzle concerns the profile of protection purchased by USAA. It is clear from Figure 1 that USAA purchases protection above a relatively small deductible. However, USAA has little protection for the largest and most severe catastrophes. (For rough magnitudes, note from Figure 3 that the AIR model shows USAA looses $242 million with probability 10% and $1 billion losses with probability 1% from hurricanes alone.) Indeed, it was not until 1997 that USAA purchased reinsurance beyond the 1% level. Is this what financial economists would expect as a risk management profile? What determines the loss level beyond which such hedging is no longer economical?

3.1.1. The optimal reinsurance profile

The first question to ask is whether USAA's purchase profile in Figure 1 differs from an optimal purchase profile, and if so, how. To do this, we derive the optimal reinsurance purchase profile in a standard model of corporate hedging. Specifically, we apply the framework of Froot, Scharfstein and Stein (1993). The basic FSS approach is that value-maximizing corporations face financing imperfections that make external capital more expensive than internal capital. Corporate hedging can raise value to the extent that it ensures that a corporation has sufficient internal funds available to take advantage of attractive investment opportunities.

Following FSS, consider a value-maximizing firm that faces financing imperfections that add to the cost of raising external funds. The future-period value of the firm is given by $P = P(w)$, where w measures the availability of internal capital. In the first period, internal capital is a random variable, in that it depends on the future realization of cat events.

The model has two time periods, present and future. In the present period, the insurer makes a reinsurance (i.e., hedging) decision regarding its catastrophic exposures by maximizing the expected value of the firm, $E[P(w)]$. The future period serves to close the model: insurers realize cat event shocks and maximize shareholder value subject to the financing imperfections they face going forward.

In the future period, a shock to the internal capital of the insurer is realized. Before hedging, the future-period internal funds are $w = w_0\varepsilon$, where w_0 is initial level of internal capital, and ε is the random negative shock from a cat event, with $\varepsilon \sim N(1, \sigma^2)$, $\forall\varepsilon \llcorner (-\infty, 1]$. To keep things simple, we choose units such that $w_0 = 1$. Thus, if there is no cat event, internal funds remain at 1.

In the first period, the insurer can purchase reinsurance against some range of event losses. Specifically, we let the insurer choose a retention, r, and a limit, l, which together define a layer of insured ε shocks, $[r - l, r] \subset (-\infty, 1]$. For simplicity, we assume the insurer buys complete reinsurance on this interval and that the reinsurance is fairly priced. We also subject the insurer to a spending constraint, B, for premiums spent on the layer.

Under these assumptions, next-period wealth is given by the shock, ε, less fair premiums, plus reinsurance claims:

$$w(\varepsilon) = \varepsilon - \left[\int_{r-l}^{r} (r-\varepsilon)dF(\varepsilon) + \int_{-\infty}^{r-l} l dF(\varepsilon)\right] + \left[(r-\varepsilon)(r-l<\varepsilon<r) + l(\varepsilon<r-l)\right], \qquad (1)$$

where r-ε is the payment under the reinsurance contract when ε falls in the region $[r - l, r]$, and l is the payment when ε is in the range $[-\infty, r - l]$.

As stated above, the future-period value of the firm is given by $P = P(w)$. Following FSS, P is assumed to satisfy $P_{ww} < 0, P_w$? 1. FSS prove that these conditions can be derived from a costly-state verification model of external financing, provided that the hazard rate of the distribution of ε, $g(\varepsilon)/(1-F(\varepsilon))$, is strictly increasing.

In the first period, the insurer chooses the reinsurance it wishes to buy by maximizing future value subject to the premium constraint:

$$\max_{r,l} E_\varepsilon[P(w(\varepsilon))]$$
$$s.t. \quad \int_{r-l}^{r} (r-\varepsilon)dF(\varepsilon) + \int_{-\infty}^{r-l} l dF(\varepsilon) \le B \qquad (2)$$

Without the budget constraint, the unconstrained insurer would set $[r - l, r] = (-\infty, 1]$. In other words, the limit would be infinite and the retention would be set at a loss of zero (with no cat event, we have _ = r = 1). The insurer would therefore be fully hedged against the cat shock. Clearly, the premium constraint is not binding unless B is strictly less than the required premium for the unconstrained contract:

$$B < \int_{-\infty}^{1} (1-\varepsilon)dF(\varepsilon) \ . \qquad (3)$$

The first-order conditions with respect to r and l are therefore:

$$-\int_{r-l}^{r} dF(\varepsilon) \int_{-\infty}^{\infty} P_w dF(\varepsilon) + \int_{r-l}^{r} P_w dF(\varepsilon) = \lambda \int_{r-l}^{r} dF(\varepsilon) \text{, and}$$
$$-\int_{-\infty}^{r-l} dF(\varepsilon) \int_{-\infty}^{\infty} P_w dF(\varepsilon) + \int_{-\infty}^{r-l} P_w dF(\varepsilon) = \lambda \int_{-\infty}^{r-l} dF(\varepsilon) . \qquad (4)$$

Combining these gives:

$$\int_{r-l}^{r} P_w dF(\varepsilon) \int_{-\infty}^{r-l} dF(\varepsilon) = \int_{-\infty}^{r-l} P_w dF(\varepsilon) \int_{r-l}^{r} dF(\varepsilon) \qquad (5)$$

Note that with the firm completely insured over the interval $[r - l, r]$, w becomes a constant over the corresponding range of ε. Thus, $w(r^*) = w(r^* - l^*)$, $\forall \varepsilon \in [r^* - l^*, r^*]$, so $P_w(w(r-l))$ can be taken out of the integral on the left-hand side. Thus,

$$\int_{-\infty}^{r-l} P_w(w(r-l))dF(\varepsilon) = \int_{-\infty}^{r-l} P_w(w(\varepsilon))dF(\varepsilon) \ . \qquad (6)$$

Since P_{ww} is negative, $P_w(w(r-l)) < P_w(w(\varepsilon)),\ \forall \varepsilon < r-l$. In other words, the greatest need to hedge, as measured by the marginal value of external funds, is greatest for the most severe risks. The only way to satisfy the equality in equation (6) is to set l to $-\times$. The spending constraint, because it is binding, then determines $r \in (-\times, 1]$.

Thus:

Proposition: When reinsurance is priced fairly, the optimal reinsurance profile protects against unboundedly large events first; the benefit of hedging higher probability layers is less. The retention is then set at lower loss levels as the spending constraint, B is relaxed. The optimal layer satisfies $[r^* - l^*, r^*] = (-\infty, z]$, where $z < 1$.

Figure 5 demonstrates the intuition for this result graphically. The shaded region shows the optimal interval over which ε is fully hedged. Larger risks are hedged first, and the retention, r, moves up continuously as the spending limit is relaxed.

3.1.2. The aggregate profile of reinsurance purchases

USAA's profile of reinsurance purchases is clearly not what one gets out of a model of corporate risk management. Is this profile common among insurance companies for their purchases of cat reinsurance? In this subsection we examine insurer hedging of catastrophe risk in the aggregate.

To determine the pattern of reinsurance purchases for a broad group of insurance companies we apply actual reinsurance transaction data obtained from Guy Carpenter & Co., the reinsurance brokerage subsidiary of Marsh McLennan Inc and by far the largest US cat risk intermediary. These data include over 4,000 cat reinsurance layers for 22 nationwide insurers and a large number of regional insurers for the years 1970 to 1998, all of which were brokered by Guy Carpenter & Co.[17]

We use these data to calculate the fraction of aggregate insurer exposure that is reinsured for different sized aggregate events. To do this, we must relate the losses on individual contracts to aggregate cat event losses. For each contract, we link individual firm retention and exhaustion loss amounts to a level of industry-wide losses. This is done using data on US regional market shares for each firm and year from A.M. Best. So, for example, a nationwide firm that has a 10% market share of cat-sensitive premiums is calculated to incur 10% of the aggregate industry losses. For such a firm, a reinsurance layer of \$100 million (limit) in excess \$150 million (retention) is calculated to provide protection for industry-wide losses of between \$1.5 billion and 2.5 billion.[18]

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[17] The CEA reinsurance is not included in this data. Furthermore, only traditional reinsurance contracts are used, so that USAA's reinsurance from Residential Re is not included.
[18] This procedure was developed in Froot and O'Connell (1997) and is discussed in detail there.

Figure 6 shows the relationship in these data between the fraction of pooled insurer exposure covered by reinsurance and the size of industry-wide events.[19] The fraction of coverage is based on marginal (not total) losses. So, for example, 50% coverage for a $3 billion national event implies that one half of an additional dollar of loss at the $3 billion level is covered by reinsurance.

There are two main points to be made from Figure 6. First, there is in the aggregate a clear resemblance to USAA's individual purchase profile. Reinsurance coverage as a fraction of exposure is high at first (after some small initial retention) and then declines markedly with the size of the event, falling to a level of less than 30% for events of only about $8 billion. Such events are not very large – aggregate statistics suggest that an $8 billion event occurs annually with probability of about 9%. So only a small fraction of large event exposures are covered, and if anything, Figure 6 *overstates* that fraction. That is because the only insurers included in the data are those that actually purchase reinsurance. The implication is that insurance companies overwhelmingly retain, rather than share, their large-event risks.

This point needs to be expanded in an important way. Insurers themselves intermediate only a small fraction of cat exposures. Many exposures faced by the corporate and household sectors are retained. Corporations, for example, tend to self-insure, and particularly so against large losses – even while purchasing insurance against small losses. Doherty and Smith (1993) document that insurance coverage is extremely limited for corporate cat losses of between $10 million and $500 million (for a single corporation) and virtually nonexistent for losses above $500 million. This suggests that the hedging profile of USAA is typical not just of the insurance industry, but of corporate insurance purchases as well. The vast majority of primitive cat risk in the economy is being retained. This suggests that lack of complete risk sharing – and the failure of the insurance and reinsurance sector to help accomplish it – is on a scale even greater than that shown in Figure 6.

There is a second point to take from Figure 6. A comparison of the reinsurance profiles at different points in time suggests that retentions increase after a large event. To see this, recall that between 1990 and 1994, Hurricane Andrew struck Florida and the Northridge earthquake occurred in California. These were by some margin the two most costly events since the 1960s. During this time period, Figure 6 shows that the fraction of exposures reinsured for medium events (between $2 billion and $8 billion) increases, while the fraction of exposures reinsured for small events (under $2 billion) actually *falls*. This is unlike the changes that occurred in previous periods. One explanation is that reinsurance contract retentions shifted upward. In other words, when coverage for large events increases after an event, it appears to do so at least partly at the expense of small-event coverage. We will provide further evidence on this point below.

3.2. Comparison with market-wide reinsurance prices

[19] Event losses are in 1994 dollars.

Next we turn to the prices paid by USAA and CEA for reinsurance. Strikingly high though the premiums may be, it is useful to be clear about the appropriate benchmark. In this section we consider two premium benchmarks: actuarially expected losses and average premiums on other reinsurance contracts.

3.2.1. Actuarially expected losses as fair-value premiums

Our use of actuarially expected losses as the fair-value benchmark hinges on two important assumptions. First, this benchmark clearly assumes that cat risk is diversifiable in equilibrium. A sufficient condition would be that the cat risk returns are independent of total wealth. Not surprisingly, the data on cat returns provide no evidence to reject this independence assumption. It should be noted, however, that existing tests examine only correlations (i.e., second and not higher moments) with other financial assets, finding them to be zero. In addition, cat events have a clear and direct effect on nonfinancial assets (e.g., housing), so correlations with financial assets may not tell the whole story.[20,21]

The second assumption we make in using actuarially expected loss as a benchmark is that our estimate of loss is unbiased. While there is uncertainty about the true probabilities, the presence of uncertainty, per se, should not matter under expected utility theory. Agents should care only about gamble outcomes provided they have unbiased estimates of outcome probabilities.[22] However, given the paucity of rich cat event data, there may be a common bias in the estimated event probabilities made by the cat models. Even if such a bias exists, it is hard understand why the capital market would think it knows more about unbiased cat-event loss probabilities than do specialized cat modeling firms. As long as the capital markets take the model expected losses to be unbiased based on currently available information, our unbiasedness assumption is satisfied.

3.2.2. The aggregate pricing of cat reinsurance

The next question is whether these individual premiums are also representative of the cat risk market. The quick answer is that they seem to fit well with historical data based on a wide cross section of cat reinsurance contracts. To demonstrate this, we again apply reinsurance contract data from Guy Carpenter and Company. As in the section above, we link these individual contracts to industry-wide losses. To calculate each contract's expected losses, however, we need an additional step. In order to assign probabilities of loss we must estimate the frequency and severity distributions of cat events. Once we

[20] See Froot, Murphy, Stern, and Usher (1995) and Litzenberger, Beaglehole, and Reynolds (1996). It is worth noting that, because of low power, there is little to be gained from investigating higher-order moments. Yet, because cat risk is highly non-normal even in continuous time, cat risk can easily alter the higher-order moments of wealth. Fortunately, for risk exposures that are small in comparison with the risk of total wealth, the effects of higher-order moments are small.

[21] In addition to the destruction of nonfinancial wealth, cat events also result in subsequent wealth transfers, and even in wealth increases for some. For example, building contractors may work longer hours as a result of a cat event.

[22] See Bantwal and Kunreuther (1999) for a discussion of departures from expected utility and its implications for cat pricing.

have estimated probabilities, it is straightforward to derive the estimated expected loss for each contract.

Figure 7 depicts the ratio of premium to estimated expected loss across reinsurance contracts. For comparison, we also graph an index of premiums relative to limit, a ratio that, in reinsurance parlance, is known as "rate on line." Here rate on line is calculated as the average across contracts of the ratio of premium to limit, and (for comparison purposes only) is set equal to the premium-to-expected-loss curve in 1989. Note that rate on line contains no calculation of expected loss, so it is immune to any measurement errors in our methodology. Of course, rate on line is also unable to provide information about shifts in retentions.

Figure 8 breaks down each treaty by layer, in order to measure premium to expected loss by exceedence probability. Higher deciles represent lower exceedence probabilities. Although not included in this database, the Residential Re and CEA layers discussed above would fall into deciles 9 or 10.

Several points emerge from Figures 6 and 7. First, reinsurance became considerably more expensive during the 1990s, with premiums rising by 3 times expected losses between 1992 and 1993 alone (contract terms for each year are set in January). This largest price increase coincides precisely with the occurrence of Hurricane Andrew in August 1992.[23] Because there were so few large storms (and none near the size of Andrew) between 1970 and 1992, it is hard to find a historical analogue to this magnitude of price increase. The next costliest US natural disaster since 1970 was the 1994 Northridge earthquake. Since that time only relatively minor insured cat losses have occurred.

Second, note that industry-wide prices on reinsurance contracts seem to match almost exactly the pricing of the 1996 CEA contract (at 6.3 times expected loss). And, if anything, they appear somewhat *low* in comparison with Residential Re in all years. Figure 8 offers an explanation for this. It shows that much of the high premium-to-expected-loss ratio (which is an average across all layers) comes from the lower-probability layers. Thus, as low-probability layers, USAA and CEA could be expected to have somewhat higher premium-to-expected-loss ratios than the average contracts graphed in Figure 7.

Third, note that prices have declined in 1998 by a factor of two from the post-Andrew-Northridge level. The decline has occurred smoothly since 1994 when measured in terms of rate on line. However, premium-to-expected-loss fell strongly only in 1998. The reason for this disparity is that the premium-to-expected-loss curve picks up changes in retention levels. As mentioned above, retention levels rose in the post-Andrew period, 1992 to 1994. From 1994 to 1997, it appears that retentions continued to rise, insofar as

[23] Hurricane Andrew and the Northridge earthquake resulted in roughly $20 billion and $13 billion, respectively, in industry-wide damages.

the rate on line curve declines while the premium-to-expected-loss curve does not. Only in 1998 do retentions begin to fall.[24]

Fourth, Figure 7 suggests a cyclical price path triggered by large events. It is argued that similar price cycles are observed in other insurance markets.[25] So even though there are not many comparable cat events in the US record, there is a strong presumption in the catastrophe marketplace that these price fluctuations are part of a kind of price "cycle."

Fifth, given the paucity of event data, one should naturally be skeptical of our (or any) estimates expected loss. After all, there is by definition little empirical information on rare catastrophic events. Even though our estimates agree broadly with those of the disaster-modeling firms, which employ different methodologies, it is possible that – across methodologies – there is a systematic underestimation of true expected losses.[26] If true, this would lead us to overstate the cost of cat reinsurance.

However, one might argue that even if the *level* of our estimates is in error, it is unlikely that the price *changes* in Figure 7 are prone to large errors. It seems hard to argue that rationally-estimated expected losses increased and then decreased so substantially over such a short period of time. If an event occurred that was thought to be of low probability, a good Bayesian with little prior information might indeed update the probability of reoccurrence. However, *nonoccurrence* of such an event would give such a Bayesian little new information since the event was unlikely to occur in the first place. Thus, it is hard to understand how any rational scheme for estimating probabilities would yield a precipitous decline as a result of a non-event. We discuss a number of hypotheses that might explain the behavior of prices in the next section.

Before leaving this point, it is interesting to note that revisions of the AIR model for constant USAA exposures downwardly adjust expected losses during this time period. Table 3 shows the decline in the event-loss distribution between the 1997 and 1999 AIR models. Even though exposure sizes increased, expected losses from the 100 basis point to 40 basis point levels of likelihood *fell* by between 10% and 14% due to model revision. While the timing of this decline may be coincidental, it is interesting to introspect on whether these same model revisions would have been implemented were a major cat event to have taken place during this period.[27]

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[24] There is preliminary evidence from the January 1999 cat reinsurance renewals that premiums and retentions have both continued to fall.

[25] For evidence of price cycles in insurance, see for example, Gron (1994).

[26] Cat modeling firms use complex Monte Carlo simulations with many sources of uncertainty and many parameterized distributions. Nevertheless they also can work only with historical data which is highly limited. For investigations of the uncertainty in cat event model estimates, see Bantwal and Kunreuther (1999), Major (1999), and Moore (1998).

[27] There is no suggestion by AIR that these changes are correlated at all with recent cat-event activity. Model refinements are a continuing process. During this two-year period, changes in the windfield generation module of the model accounted for much of the decline in expected loss. This module "was enhanced to provide for smoother transitions between the filling rates from one region to another and to update surface friction factors.... In addition, an updated coastline [data] file was implemented..." (Residential Re 1999 offering circular, p. 47). Both changes reduced expected losses, but neither is explicitly motivated by recent event occurrence.

Even with the model changes, the USAA ratio of premium-to-expected-loss ratio declines. However, it does so only slightly, falling from 9.1 in 1997 to 8.3 in 1999. Thus, recent premiums do appear to decline when changes in expected losses are taken into account. But the changes in the AIR model leave one suspicious about how much weight the modeling process places on very recent (non) events. Much of what appears to be a change in premium-to-expected-loss ratios in Figure 7 may instead be a change in perceived event probabilities.

3.3. Summary

To conclude, the agreement between different measures of expected loss in Figure 7, and the CEA and USAA contracts is strong. It seems clear that the two puzzling aspects of these layers – the relatively small amount of reinsurance for large events and high prices – have been pervasive across the catastrophe risk market. In the next section, we consider a number of different explanations that may help explain these puzzles. The goal here is not to provide comprehensive evidence on each of these possible explanations, but to identify and clarify hypotheses.

4. Explanations and Interpretations[28]

Our explanations are of two types: those that affect supply and those that affect demand. Taking the two findings above as given – that reinsurance quantities are low and prices high – naturally suggests some form of supply restriction. However, there is unlikely to be a single explanation, and several demand-related explanations appear to be supported by some of the evidence as well. Thus, we consider factors that affect both demand and supply.

4.1. Explanation 1: Insufficient capital in reinsurance

Perhaps the supply of reinsurance is low because catastrophic risk-taking capital is somehow inhibited. In other words, there may be financing imperfections similar to that in the model above. Such capacity shortfalls, even if relatively temporary, might exist for a number of structural reasons: it may be costly for existing reinsurers to raise additional funds in the capital markets; it may be hard to find investors who expect appropriate "equilibrium" rewards for bearing catastrophic risks; it may also be that it is costly for reinsurers to hold large amounts of collateral on their balance sheets. What is the evidence that reinsurance capital is in short supply?

First, judging from Warren Buffett's writings, shortages of capital appear to be an important rationale for Berkshire Hathaway's reinsurance strategy. In his 1996 letter to shareholders, Buffett observes,

> "Our ... competitive advantage [in writing "supercat" risks] is that we can provide dollar coverages of a size neither matched nor approached elsewhere in the

[28] Parts of this section draw upon Froot (1999a).

> industry. Insurers looking for huge covers know that a single call to Berkshire will produce a firm and immediate offering."

Perfect access to capital by new and existing reinsurers would remove this "competitive advantage." So it seems Buffett believes in – and pursues a strategy of exploiting – capital shortfalls.

Buffett's strategy is also predicated on a perception that a capacity shortage may become temporarily worse, for example, if reinsurer capital is depleted by a large event. A temporary shortage would be consistent with the post-event cycle suggested by Figure 7, wherein prices rise and then fall while quantities fall and then rise. Again from Berkshire Hathaway's 1996 annual report, Buffett writes:

> "After a mega-catastrophe, insurers might well find it difficult to obtain reinsurance even though their need for coverage would then be particularly great. At such a time ... it will naturally be [Berkshire's] long-standing clients that have first call on it. That business reality has made major insurers and reinsurers throughout the world realize the desirability of doing business with us. Indeed, we are currently getting sizable 'stand-by fees from reinsurers that are simply nailing down their ability to get coverage from us should the market tighten."

Buffett seems to be saying that the *prospect* of a capital shortage in the aftermath of a major cat event motivates insurers to purchase 'capacity' protection. Note that this is not protection against an increase in prices – presumably National Indemnity's clients would pay the going market rate – but protection against being excluded from the marketplace. The price of a guarantee to participate in a well-functioning marketplace should be zero.

In both of these quotes, and in other discussions of "supercat" risks in Berkshire Hathaway annual reports from 1995, 1996, and 1997, Buffett emphasizes the value to Berkshire's shareholders of the company's substantial balance sheet. In a world of costless access to external finance, a balance sheet earns no rents by virtue of its size. It therefore ought to bestow no competitive advantage on those who control them.

Buffett's emphasis on quantity shortages, and not price increases, is important for making an argument on financial imperfections. It is consistent with the low level of risk transfer and post-event decline in quantities – both shown in Figure 6. It also avoids reliance on the price evidence we have seen so far (e.g., Figures 6 and 7). As we mentioned above, this price evidence can be distorted by unobserved variation in subjective event probabilities (such as those driving the updates in the AIR model). It is the weakest link in the argument. So isn't there a way to test whether prices comove inversely with quantities, in a way that is not subject to the probability-updating critique? If so, we would have more decisive evidence that capacity shifts lie behind price movements and levels.

It turns out the answer to this question is yes. Suppose we were to observe a large hurricane that subsequently increased reinsurance premiums. The probability updating hypothesis would say that the change is due to learning about the future damages associated with hurricanes (fully rational or not). We would therefore expect the premiums on hurricane risk to change, and probably to rise. At the same time, would we have learned nothing about the probabilities of loss on independent perils, such as earthquakes. Thus, under the probability updating hypothesis, the premiums on earthquake risk in California should remain constant. Alternatively if the post-hurricane price increase is a result of capital market imperfections, we would expect an increase in both hurricane *and* earthquake premiums. Thus, if we can divide up the post-event cross-section into different peril combinations, we can perform a kind of event study to better test the comovement of prices and quantities.

Table 3 provides the results of such an event study. The table shows both price and quantity responses in reinsurance purchased during the year following hurricane Andrew. As before, reinsurance quantity is measured as actuarially expected loss. We already know that in aftermath of Hurricane Andrew, reinsurance purchases fell, and that this occurred primarily through an increase in retentions. Table 3 adds the fact that the quantity purchased *fell* by more – and the premium paid *rose* by more – for those insurers that had greater exposure to the Southeastern US and to hurricanes wherever they occur.

Thus, across contracts, prices rise most where quantities decline most. It seems hard to explain this fact by a subjective increase in probabilities, provided that the probability increases retain some bearing to the information revealed in the event. Thus, while there may be some probability updating that we cannot capture in our unconditional estimates of expected loss, there also appears to be a strong element of true price increase. This can only be explained by a temporary, shift backward in the supply of capital.

Of course, it is not surprising that the supply of cat risk bearing capital is momentarily restricted immediately following an event. Large-event losses deplete reinsurer capital and surplus and, realistically, require at least a short amount time to replenish. However, 6 years elapsed between Andrew and the first declines in the premium-to-expected-loss ratios in Figure 7. The timing therefore also seems consistent with the hypothesis that frictions retard capital flows into the reinsurance sector.[29]

The final point in this section is that there is a kind of irony in the financing imperfections story as applied to insurance and reinsurance: much primitive cat risk could be reduced through investments in mitigation, investments that would appear to pay high actuarial returns. However, many of these investments are not made because they require individuals and corporations, who have scarce capital themselves, to raise (or deplete internal) capital. Thus, capital market shortages may in part be responsible for the large

[29] It is common in the industry for reinsurers to require "paybacks" for event losses and to do so through higher premiums and retentions. Note that there is nothing in this practice, to the extent it explains the data, to contradict explanation #1. However, an important question remains as to why this kind of contracting prevails and what it tells us about reinsurance markets. See explanation #5 below for one potential answer.

and growing risk pool needing insurance and reinsurance. Without capital shortages, reinsurance capacity could costlessly be greater, but there would also be fewer risks to reinsure in the first place.[30]

To conclude, the post-Andrew decline in premiums has not altogether escaped Warren Buffett's attention. He offers his own explanation in his 1997 annual letter:

> "Many investors who are 'innocents' – meaning that they rely on representations of salespeople rather than on underwriting knowledge of their own – have come into the reinsurance business by means of purchasing pieces of paper that are called 'catastrophe bonds.' ...The influx of 'investor' money into catastrophe bonds – which may well live up to their name – has caused super-cat prices to deteriorate materially."

Clearly, Buffett believes that a capacity expansion, not a change in true probabilities, is the cause for the decline in premiums. Understandable, but less than fully credible, is his claim that this expansion is the result of misinformation rather than better risk sharing and greater competition.

4.2. Explanation 2: Reinsurers have market power

A number of observers have suggested that the evidence on prices and quantities above might be explained by market power rather than by a capital shortage per se. Under this explanation, prices rise and quantities decline not because reinsurance capital is impossible or costly to obtain, but because existing reinsurers have no incentive to increase their capital. By putting less money at risk and preventing new entry, incumbent reinsurers keep prices high. Some observers, such as James M. Stone of Plymouth Rock Company (a former Harvard Professor of Economics and Massachusetts Insurance Commissioner), argue that market power among reinsurers is the main reason that catastrophe reinsurance has proved a more attractive business than insurance.

Of course, it is very hard to provide evidence that market power among reinsurers has increased secularly over time or cyclically in the aftermath of events. There is a general view that the reinsurance industry has been consolidating. There has been a distinct drop, for example, in the number of Lloyd's syndicates since the 1960s and 1970s. There has also been an increase over time in the capital and market share of large reinsurers. However, these facts aren't necessarily associated with increased market power in setting prices or restricting supply. For example, even though there are fewer Lloyd's syndicates, catastrophic risk pricing is not typically determined by individual syndicates.

Furthermore, while consolidation has occurred in the industry, greater market power need not be the driving force. Consolidation may result from economies of scale. The information-intensity of reinsurance is one possible source of scale economies. For

[30] See Howard Kunreuther and Paul Kleindorfer, "Challenges facing the insurance industry in managing catastrophe risks," NBER conference on The Financing of Property/Casualty Risks.

example, there may be high fixed costs of developing analytic capabilities and systems.[31] Once these systems are in place, optimal reinsurer size grows as the required investment in fixed-cost systems increases. Consolidation may also be an efficient industry response to costs of obtaining outside capital. If those costs are partially fixed, or proportionately decline with size, the amount of outside capital may also be a source of increasing returns.

Barriers to entry are another place to look for market power. Clearly, the barriers to buying a cat bond are lower than the barriers to underwriting reinsurance. This is not surprising, given that the cedent does not bear the bondholder's credit risk, but is forced to bear the reinsurance underwriter's credit risk. Even so, there is considerable evidence of entry into reinsurance in the 1990s. For example, beginning in 1993 at least 6 major reinsurance companies were formed in Bermuda, representing over $7 billion in new reinsurance capital. (The first of these companies, Ace, XL, and Mid Ocean Re, were organized prior to Hurricane Andrew, and so cannot be construed as a response to that event, per se.) While the barriers to entry may be high for some agents (e.g., individual or institutional investors), Bermuda is evidence that the barriers are not uniformly high for all groups.

Still, it is interesting to speculate about the role of market power in the steep 1998 price decline shown in Figure 7. After all, not much new capital was injected into traditional reinsurers in 1997 or 1998. It's true that during this time, reinsurer balance sheets grew marginally with premiums and interest, while experiencing trivial event losses. But the same was true for each year since 1994. Similarly, the cat bonds issued in 1997 and 1998 may have been innovative, but they accounted at most for only a few percent of total cat reinsurance treaties (based on limit). Thus, there has been surprisingly little change in reinsurance capacity since 1995.

Probably the best explanation for the magnitude and timing of the recent price decline is a change not in capacity, but in *contestability*. While a large amount of new capacity may be needed to drive down prices in a competitive market, the same is not true when producers are perceived to have market power. In that case, all that is required is to increase the perceived level of competition. This fits with the cat bond experience. While cat bond issuance has been quite small, it began to seem intensely interesting and important beginning in mid 1997 with Residential Re I. Furthermore, Warren Buffett's final remark in the previous subsection seems to assign disproportionate importance to cat bonds; it is hard to imagine Buffett going out of his way to acknowledge (and discredit) other traditional sources of cat capacity at all, never mind a source of such tiny size. The conclusion we draw is that cat bonds have affected markets well beyond the size of the actual issues. It seems market power stories can explain a few of the facts we have identified, and therefore ought to be taken seriously.

4.3. Explanation 3: The corporate form for reinsurance is inefficient

[31] Comments by Stewart Myers, in Froot (1999b), pp. 434-437.

Under this explanation, the corporate organizational form of reinsurers is unnecessarily costly. Observers of corporate governance often point out that there are costs associated with discretion given to managers to run a business. In principal, managers could pursue objectives other than value maximization. It may be difficult for shareholders to identify and discipline this behavior. Even if most managers are benevolent, the prospect that a bad manager might use his agency relationship against shareholders reduces stock prices and drives up the cost of capital.

This generic corporate finance argument of "agency costs" has application in a number of arenas. First, it clearly can be applied to insurers and reinsurers. Many of the details of the reinsurance business and the specific contracts are not transparent to arm's-length capital providers. And, given the occasional-big-loss nature of reinsurance, it takes many years to evaluate management efficacy and true business profitability. In reinsurance, managers may have an unusually large incentive to gain market share (and increase their size) by cutting premiums beyond that called for by shareholder value maximization.

How costly is it to delegate discretion to managers? This is generally a difficult question to answer. However, for some narrowly-defined businesses it is possible to get a partial answer. Closed-end funds are one such business. Closed-end funds invest in publicly traded securities and then sell stakes in their portfolio to shareholders, much like mutual funds do. However, unlike "open-ended" funds, closed-end-fund portfolios are not affected by fund purchases or redemptions; shareholders buy and sell shares among one another, without the fund involved. Thus, the price of the closed-end-fund shares, like the price of most traded stocks, must find its own value in the marketplace in accord with supply and demand.

As is well known, there is a puzzle associated with closed-end fund shares: their prices are, on average, considerably below their net asset values.[32] This cannot happen with open-ended fund shares. Closed-end share discounts average about 10%-20%, and are fairly pervasive across funds and over time. It is often argued that agency costs account for these discounts.[33] The agency story is that closed-end funds must pay an average return in excess of what would be required for holding the underlying net assets. The reason is that shareholders can't directly observe or discipline managers. Thus there is a bias toward managerial decisions that put the managers' interests above those of shareholders.

The agency cost argument may explain why the costs of reinsurance capital, and by inference, reinsurance prices, are high. The argument is buttressed by two regularities. The first is that reinsurance managers regard their capital costs as "equity-like" – i.e., as requiring a return considerably above US Treasury rates. An actuarially fair premium is viewed as beneath the hurdle rate imposed by shareholders. Yet, given that catastrophe risks are uncorrelated with those of other financial assets, shareholders' required returns on cat risk should, as argued above, be low. Agency costs may be one factor forcing up required returns. The agency cost explanation may therefore help understand the view in

[32] See Lee, Shleifer, and Thaler (1991) for a general discussion of the closed-end fund puzzle.
[33] Citation?

the industry that, for many risks, there is "too much" capital and that prices are "too low." Indeed, some public reinsurers have recently been repurchasing stock on the argument that premiums are too low, and therefore do not meet shareholders hurdle rate.

There is a second regularity behind the view that reinsurers are an inefficient corporate form. This is that, even without agency costs, there is evidence that shareholders expect reinsurer equity returns to be well above US Treasury rates. Evidence for this comes from the behavior of stock prices of public Bermudan reinsurers, such as Mid-Ocean Ltd. (recently purchased by XL), Renaissance Re, and Partner Re. These firms hold large property/catastrophe liabilities, and historically have held assets in the form of short-term notes and bills. Neither their assets nor liabilities are correlated with the stock market, yet their share prices comove positively with the stock market. Specifically, a 10% increase in the level of the S&P 500 is associated with an increase in the average value of these firms of about 6.5%.[34] We cannot identify a source of this comovement that emanates from the companies themselves.

While it is interesting to speculate on the source of this distortion (e.g., noise, liquidity, etc.?), the point here is to ask how reinsurance managers ought to respond. Clearly, investors *should* require a higher return on these stocks *if* their prices will move with the market. And, as a result, value maximizing reinsurance managers *should* inherit higher hurdle rates, setting premiums above actuarial value.[35] This argument suggests that equity-financed reinsurance may be inefficient even in the absence of agency costs. If equity capital requires a high return and reinsurer assets and liabilities contain no broad equity market risks, then equity is an expensive form of capital, pure and simple. And if reinsurance is financed in an expensive manner, reinsurance prices will be high.

Note the relationship between this argument and explanation 1 above. Reinsurance companies may experience financial distress and other deadweight costs of raising outside capital. Such costs clearly add to the cost of capital, thereby driving up reinsurance premiums. This story is really a version of explanation 1, but it can also be construed as an inefficiency in reinsurers' corporate form. What we have added to this under explanation 3 is that an inefficiency in equity markets may be responsible for the added costs.

Offsetting our arguments about inefficiency, however, is a view articulated by Roberto Mendoza of J.P. Morgan. The view is, first, that Bermuda's zero rate of corporate income tax reduces reinsurers' costs of equity. With no income tax, reinsurers would gain little by substituting debt for equity finance, since there are no interest tax deductions available to them in the first place. Furthermore, Bermudan reinsurers provide shareholders with an

[34] Data on unadjusted stock betas from Bloomberg.

[35] Of course, if it were feasible, the first-best response would be to remove the underlying distortion altogether. If, for example, the market exposures of the stock prices were immutable and fixed, then it would be best for managers to increase the equity exposure of their assets, so that the firms' true asset betas corresponded with the fixed betas assigned by the market. Then there would be no need to increase the hurdle rate on cat reinsurance. Alternatively, managers could potentially substitute debt finance for equity to avoid the "high" costs of equity.

opportunity to achieve tax-free compounding on invested capital. This tends to lower the cost of equity relative to what it would otherwise be.

Second, Mendoza argues that managerial discretion may provide an "agency benefit" in the case of cat reinsurance. In a highly inefficient and specialized market, shareholders need an experienced agent to cherry picking risk-writing opportunities.[36] In this case, the present value of the managerial discretion is positive, since it allows shareholders to exploit reinsurance market inefficiencies.

If true, Mendoza's arguments suggest that the corporate form of reinsurers, particularly those in Bermuda, is actually a highly efficient delivery mechanism for reinsurance risk.

4.4. Explanation 4: The frictional costs of reinsurance are high

This explanation says that prices are high because, as financial instruments, reinsurance contracts are illiquid, have high transactions costs, brokerage, etc. These sources of friction imply that there are important costs in getting capital and reinsurance contracts together in a repository called a reinsurer.

There is abundant evidence that illiquid assets trade at significant discounts. Letter stock, as one example, typically trades at discounts of 25% versus publicly-traded stock; on-the-run bonds trade at significant premiums versus less liquid off-the-run bonds; and so on. However, illiquidity of one-year reinsurance contracts is not enough to drive up premiums. Part of the reason for capitalizing reinsurers who hold short-term notes for assets is to enable reinsurers to provide liquidity to insurers' risk exposures. In order to raise reinsurers' cost of capital, their own placements would need to be discounted for illiquidity. This may arguably have been the case for Lloyd's commitments from individual names; it is far less compelling for publicly traded reinsurers in Europe, the US, and Bermuda.

Other frictions such as brokerage costs and servicing expenses can legitimately raise the cost of procuring reinsurance. However, these costs are not out of line with other financing charges. For example, in the National Indemnity transaction described above, annual brokerage fees were less than 1% of premium, and therefore, were about 11bp of limit. If the reinsurance had been issued as a capital market instrument, as had been anticipated by some, these costs would have amounted to about 5% of annual premium, or approximately 55bp of limit. In fact, the fees associated with 1997 Residential Re bond offerings came to approximately 100bp of limit.[37] Thus, if anything, the traditional reinsurance brokerage and issuance expenses are lower than standard capital-market fees.

Furthermore, the high level of prices seems well above anything that can be explained by brokerage and underwriting costs. Even if brokerage and underwriting expenses had come to a high of 10% of premium in the National Indemnity deal, complete elimination

[36] Of course, the same argument is often made in defense of closed-end fund managers.

[37] See Moore (1998).

of these expenses would have driven down the multiple of premium relative to actuarially expected losses by about 0.6 from 5.3 to 4.7. Brokerage and underwriting expenses cannot explain observed price levels.

Another kind of frictional inefficiency is the means by which reinsurers manage risk. Reinsurers manage their risk by aggregate (notional) limits, rather than exposures. For example, a reinsurer might decide it will risk up to $100 million on Florida, but without specifying the distribution of Florida losses on contracts written, or the covariance of Florida losses with potential losses on its North Carolina contracts. Removing such portfolio inefficiencies could have a substantial impact on the cost of risk transfer.

Better reinsurer risk allocation can reduce the cost of capital if reinsurers face financing imperfections, as in explanation 1. A poorly diversified portfolio of reinsurance adds needlessly to risk, and risk to internal capital is costly if there are financing imperfections. As a result, there is a kind of interaction effect between this explanation and explanation 1 above: costs of external finance can magnify the impact of poor diversification on reinsurer capital costs. This might be a more promising place to look for frictional inefficiencies in reinsurance intermediation, but only if one accepts the notion of financing imperfections in the first place.

4.5. Explanation 5: Markets are degraded by moral hazard and adverse selection

Moral hazard and adverse selection are often singled out as distortions that prevent markets from functioning efficiently. In general these distortions suggest that risks should be disproportionately borne by those who control them and/or know them best. Clearly, these effects restrict reinsurance supply. So they may help explain some of the facts we observe.[38]

Market participants also claim that there is evidence for the presence of moral hazard and adverse selection in reinsurance market conventions. Often an explicit reinsurance contract contains an implicit agreement that reinsurers will charge more in the aftermath of a claim and that the cedent will continue to buy reinsurance from the same underwriter. Under this interpretation, property / catastrophe reinsurance is an implicit form of "finite" reinsurance. Finite reinsurance does not so much transfer risk from the cedent, as it finances the cedent. During an event, the reinsurer makes funds available, expecting to be paid back later through higher subsequent premiums. In its purist form, the arrangement is just event-contingent borrowing.[39]

This interpretation of our evidence of cat reinsurance is interesting and far-reaching. First, it suggests that there may be even less risk transfer than we thought. The numbers in Figure 6, for example, are overstated, since they do not account for the present value of

[38] In some circumstances, higher prices may actually exacerbate the problem, making it impossible for the market to function. For a discussion of the implications of adverse selection on reinsurance contracts, see David Cutler and Richard Zeckhauser (1999).

[39] The contingent credit arranged for the Nationwide by J.P. Morgan has many of these features.

claim repayment. Second, the price and retention cycle we have seen subsequent to Hurricane Andrew are not evidence of explanations 1, 2, 3 or 4. Instead, they become evidence of a kind of "repayment cycle," where post-event periods are characterized by more rapid repayment for past claims.

While it has a number of virtues in explaining the evidence, this explanation has two basic flaws. First, there is the question of time-consistency. What disciplines a cedent from switching reinsurers after making a claim? Since there is no contractual obligation to the original underwriter(s), the only way reinsurers could enforce repayment is through implicit collusion and barriers to entry into reinsurance. And, as we have already seen, market power by itself (even in the absence of moral hazard and adverse selection) can go a long way toward explaining the facts. This does not rule out explanation 5, it only says that believers have to acknowledge support for explanation 2 as well.

Second, moral hazard and adverse selection seem relatively harmless for cat reinsurance as compared with other forms of insurance and reinsurance. Product liability protection, for example, can be understandably plagued with asymmetric information and moral hazard. Given the disclosure requirements, the large number of small risk units (i.e., houses, autos, etc.), and the presence of third-party modeling expertise for cat risk, it is hard to see how these distortions could be important.

Finally, the high deductible and coinsurance in virtually all of these contracts reduces the scope for moral hazard and adverse selection. Indeed, the evidence in Figure 8 suggests that the pricing is most elevated at high layers where exceedence probabilities are low. Moral hazard and adverse selection problems would not predict this. Indeed, retentions and lows layers ought to be the most affected by moral hazard and adverse selection, so these effects imply that lower layers should less efficient.

4.6. Explanation 6: Insurance regulation discourages the purchase of reinsurance

This explanation begins with the observation that many states use regulatory barriers to keep insurance prices down. In some states, lines of business, and specific geographic areas, insurers must underwrite the cat component of risk at prices that are well below those that are actuarially and financially profitable. This is perhaps not a surprising state of affairs given that insurance commissioners are publicly elected officials in 12 states, including California and Florida.

Clearly this story cannot explain a high level of prices in the reinsurance market. However, it can explain why there is so little reinsurance purchased, even if prices are actuarially fair. The basic reasoning is that if insurers are unable to earn a profitable return by underwriting risk, they need to cut costs. One way of cutting costs is to avoid purchasing reinsurance in a way that is consistent with profit maximization.

The mechanism here is similar to that of rent control. Rent control makes housing cheaper in the short run. But in the longer run, it cannot affect the equilibrium rental rate.

Thus, if rents can't adjust upward, the value of the housing stock adjusts downward through depreciation in quality.

In response to price controls, value-maximizing insurers will necessarily produce a product that has lower quality and higher risk. Price controls reduce going-concern value and increase insurer leverage considerably.[40] Insurer equity becomes more like an out-of-the-money option. As a result, the demand to hedge risk with reinsurance is reduced. The result is that state guarantee funds must bear considerably greater risks that a large catastrophe will become their responsibility or the responsibility of policyholders, taxpayers, and/or remaining insurers. In short, everyone suffers if regulation makes it unprofitable for insurers to provide high quality insurance contracts.

This explanation fits the cyclical behavior of quantities in addition to their low average level. After a big event, there is political pressure to expand the scope of insurance without raising its cost. If prices are cut through the regulatory process, insurers will cut back on reinsurance purchases, even if the reinsurance is offered at a fair price.

The major weakness of this explanation is that it cannot explain high reinsurance premiums. However, it does explain why insurers may perceive reinsurance prices as "high," i.e., in excess of what they can profitably afford to pay.

4.7. Explanation 7: Ex-post intervention by third-parties substitutes for insurance

Ex-post financing of catastrophes occurs when other parties step in to transfer funds to those who experienced event losses. Chief among these entities is, of course, the US government. As is well known, the government has a major role in funding disasters at both state and federal levels, through a number of agencies, and through both the executive and legislative branches. Since the late 1970s, the Federal government has spent annually an average of $8 billion (current) dollars on disaster assistance. This is far greater than the average annual loss borne by reinsurers on US catastrophe coverage. In some forms of disasters, notably floods, the federal government has effectively eliminated the incentive for private insurance contracts. Indeed, before the Federal government stepped in to provide disaster relief, private insurers *did* offer flood insurance.[41]

The federal government is not the only entity involved in ex-post financing of catastrophes. State guarantee funds are often the next line of defense if an insurer is unable to meet its policy liabilities. And if the state fund is exhausted, then solvent insurance companies are often required to make up the difference. This creates two types of bad incentives. First, companies have an incentive to shift the burden onto the fund or other insurers before the fund is exhausted. Second, companies who do not act to shift high layer losses onto the pool are themselves likely to have to pay for others. Well-behaved insurers will wish to avoid doing business in states with guarantees funds and

[40] Even without debt capital, insurers have plenty of financial leverage because of policyholder liabilities.
[41] See Moss (1996).

pools. This strengthens the need for regulation and can create a kind of vicious cycle in market vs. regulatory incentives.

From an economist's perspective, such ex-post financing should be viewed as a form of market failure. The federal government cannot credibly commit *not* to fund disasters after the fact: even if it says it will not provide disaster relief *ex ante*, the political incentives to do so *ex post* are overwhelming. Given this, the demand for purchasing an insurance contract is reduced.

It is therefore clear how ex-post financing affects the price and quantity of reinsurance. The effect on quantity is strongly negative, for both insurance and reinsurance. As with explanation 6, ex-post intervention by third parties cannot explain why prices are high. It can, however, explain why insurers perceive that reinsurance prices are high. It can also explain low quantities of high-layer reinsurance and the cyclical downturns in quantities after major events.

4.8. Explanation 8: Behavioral factors dampen demand

A commonly cited reason for the low quantity of high-layer reinsurance is that the *perceived* likelihood that reinsurance will pay is too low to matter. For those who use expected utility-based or profit-maximization approaches – such as that in section 2.1 above – insurance against severe, low-probability events is most valuable. But behavioralists have suggested that expected utility approaches fail to describe decision making.

One important failure is that people discount too heavily events they cannot readily perceive. For example, a famous study from the 1970s shows that the rate of smoking is higher among the general populace than among doctors (general practitioners), higher among general practitioners than among internists, and higher among internists than among specialists who work directly with lung cancer patients. Even when the consequences and probabilities of bad outcomes are well known, it takes repeated hammering home of bad outcomes to affect behavior.[42]

A second behavioral effect is that individuals often seem "ambiguity" averse. A lack of clarity about the risks and events being insured may lead insurers and reinsurers to set premiums high.[43] Behaviorally, people seem to distinguish between risk (where probabilities are known) and uncertainty (where they are not). Uncertainty is inherently more ambiguous, and surveys suggest that individuals charge more to bear it.

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[42] See Tamerin and Resnik (1972) and Kunreuther et al (1978).

[43] See Howard Kunreuther, Robin Hogarth, and Jacqueline Meszaros, "Insurer ambiguity and market failure," *Journal of Risk and Uncertainty*, 7:71-87 (1993).

5. Conclusions

This paper has shown that reinsurance premiums are coming down and that the market is becoming more competitive, while capacity is increasingly available since the time of Hurricane Andrew. With time, USAA and other firms have begun purchasing more coverage for the largest events. So the movement is in the direction predicted by our model. Indeed, it is interesting to ask what, in equilibrium, determines the probability level beyond which reinsurance becomes uneconomic. All of the explanations we explore would seem to have a role in this.

What important lessons can we take from the evidence? After all, the cat risk market is small – traded notional exposures probably are in the (low) hundreds of billions, not the trillions as in major credit, mortgage prepayment, and straight debt markets.

First, we learn something about capital markets and intermediary structure. It is clear from what we have seen that securitization is not automatically the lowest-cost way to transfer risk. Why is this? Principals with wealth often hire dedicated agents to manage their portfolio. If there are corporate taxes then it makes sense to install the agent as the manager of a mutual fund pass-through that buys securities but pays no taxes. However, if there are no corporate income taxes, then there is little difference between a mutual fund buying securities and a corporate reinsurer underwriting reinsurance. Thus, it isn't so wrong to think of reinsurers in tax havens as investment advisors for infinitely-lived closed-end mutual funds. From a capital markets perspective, there is nothing dramatically inefficient with this, provided that the principals care little about the liquidity of this small part of their portfolio, and therefore are indifferent to the liquidity of reinsurance contracts versus cat bonds. From a corporate perspective, the closed-end fund version avoids costs of financial distress, but it must distribute its income, and therefore cannot legally achieve the tax-free compounding available to Bermudan reinsurers.

Second, we learn something about corporate risk management. Because managers of insurance companies purchase reinsurance at far above the fair price, they clearly must believe that risk management adds value. This statement is not easy to make in other markets, since it is so hard to measure the value of corporate risk management, and since Modigliani Miller can accommodate *any* risk management policy when prices are fair. Of course, these conclusions follow from the assertion that fair prices can be more credibly measured for cat events than for other, less objectively-modeled exposures.

Finally, the facts support the idea that there are capital market imperfections or barriers to capital entering into reinsurance. Cat bonds tend to lower, but not eliminate, these barriers. This may be because of friction capital-raising costs, but also because it is difficult to remove transparency in new products without an investment of time and energy on the part of investors. As a result, cat premiums may continue to decline, but it is unlikely they will permanently reach the level of expected loss.

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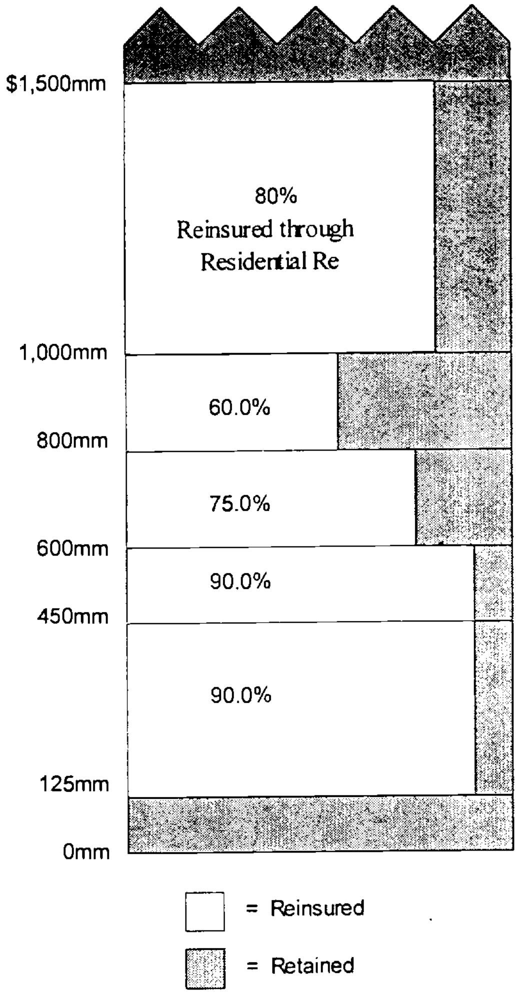
Figure 1 USAA's 1997 Reinsurance Program (contracts in force from July 1997 to June 1998)[44]



Layer #	Annual Premium	Illustrative ROL	Comments
5	$24.0mm*	6.0%*	securitized by Residential Re
4	$6.6mm	5.5%	Excludes California and Autos
3	$15.0mm	10.0%	Excludes Autos
2	$16.9mm	12.5%	Excludes Autos
1	$24.4mm	7.5%	FHCF Hurricanes in FL Only

Calculation of ROL for Layer 2

Premium Paid: $16.9mm

Limit: 90%*(600-450)
= 90%*(150)
= $135.0mm

ROL: Premium / Limit
= $16.9mm / $135.0mm
= 12.5%

Calculation of premium to expected loss for Layer 2

ROL of Layer 2: 12.5%

Actuarial Prob. of Loss > $450mm: 4.5%

$$\text{Price: } = \frac{12.5\%}{4.5\%} = 2.8$$

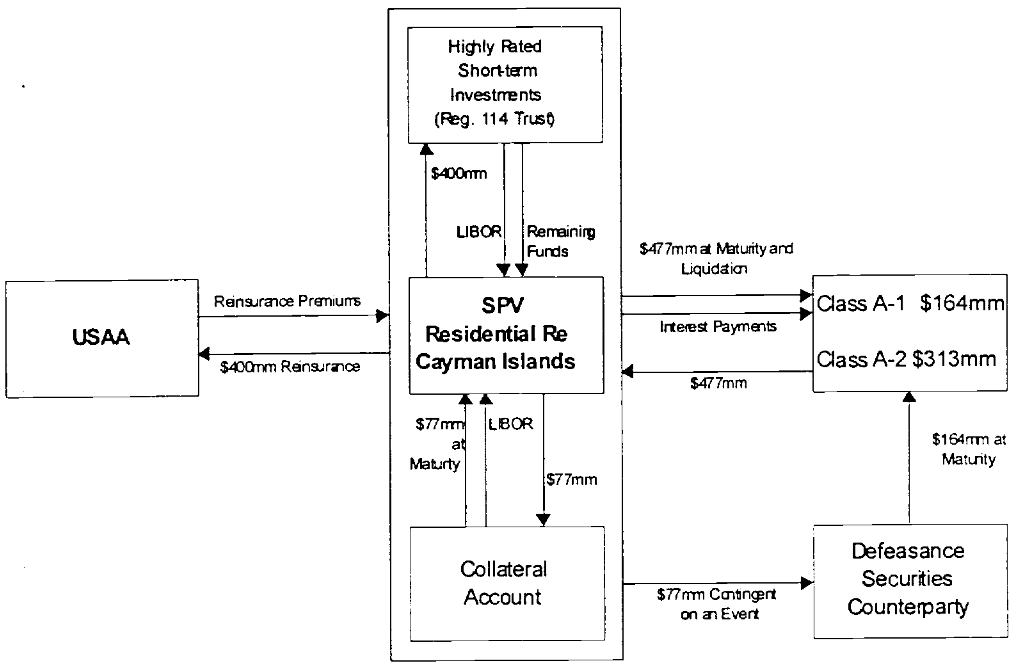
* Rumors in the market were that Layer 5 would cost approximately 5% ROL for traditional reinsurance (private communication with Guy Carpenter, Inc. brokers.)

[44] With the exception of the top layer reinsured by Residential Re, the premiums and illustrative ROLs shown in this exhibit are *not* the prices and rates paid by USAA. Due to the sensitive nature of the information, only illustrative rates have been provided.

Table 1 Residential Reinsurance, Cat Bond Contract Specifications

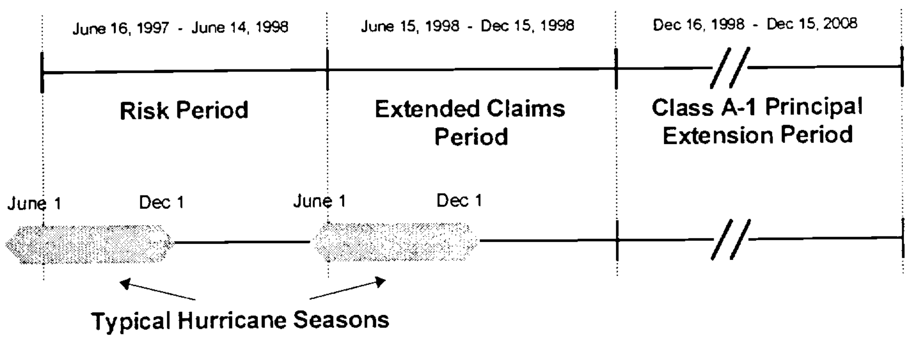
Obligor:	Residential Reinsurance Limited, a Cayman Island reinsurance company, whose sole purpose is to provide reinsurance for USAA		
Amount:	Class A-1:	$164mm	$87mm principal variable $77mm principal protected
	Class A-2:	$313mm	100% principal variable
Yield:	LIBOR + 576 basis points		
Loss Occurrence:	One Category 3, 4, or 5 hurricane		
Reinsurance Agreement:	Residential Reinsurance Limited will enter into a reinsurance agreement with USAA to cover approximately 80% of the $500mm layer of risk in the excess of the first $1,000mm of USAA's Ultimate Net Loss		
Ultimate Net Loss:	Ultimate Net Loss = amount calculated in Step 6 (below) Step 1 All losses under existing policies and renewals Step 2 All losses under new policies Step 3 9% of the amount calculated in Step 1 Step 4 Add the amount from Step 1 with the lesser of Step 2 & 3 Step 5 Multiply Step 4 by 1.02 for boat and marine policies Step 6 Multiply Step 5 by 1.02 to represent loss adjustments		
Coverage Type:	Single occurrence		
Coverage Period:	June 16, 1997 to June 14, 1998 (see Figure 2b)		
Ratings:	Class A-1:	Rated AAAr/Aaa/AAA/AAA by S&P, Moody's, Fitch, and D&P, respectively	
	Class A-2:	Principal variable notes are rated BB/Ba/BB/BB by S&P, Moody's, Fitch, and D&P, respectively	
Covered States:	Alabama, Connecticut, Delaware, District of Columbia, Florida, Georgia, Louisiana, Maine, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Texas, Vermont, and Virginia		

Figure 2a Structure of the 1997 Residential Re Transaction



Source: Goldman Sachs.

Figure 2b Time Line for Residential Re Contracts

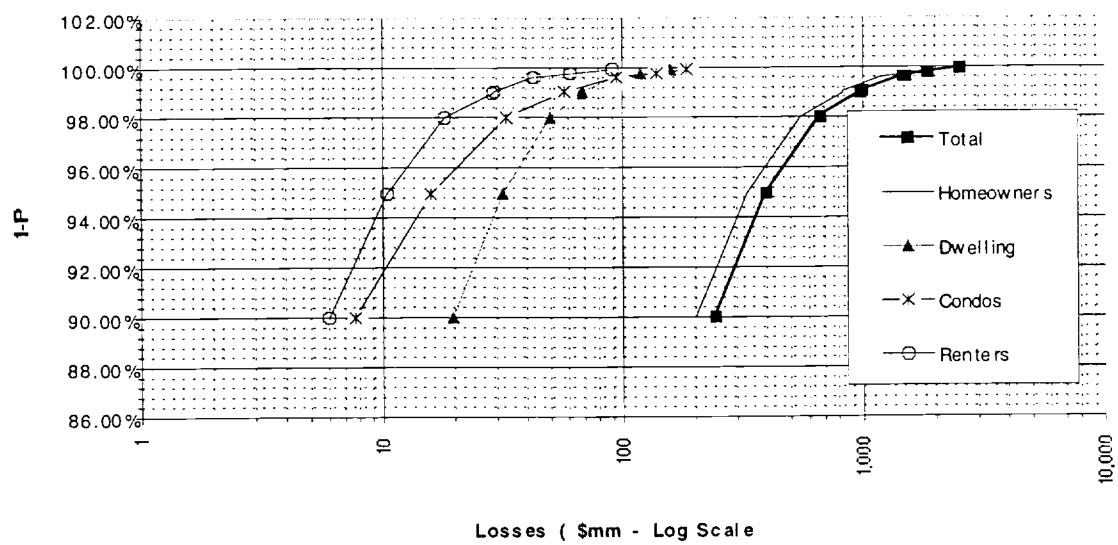


Source: Residential Re offering memorandum.

Figure 3 Estimated Probabilities of Hurricane Losses for USAA ($mm - from simulations)[45, 46]

P Annual Probability that USAA Losses are Greater Than Amounts in Column 3 (1)	1-P (2)	Total Losses (not additive) (3)	Home Owners (4)	Dwelling (5)	Condos (6)	Renters (7)
10.00%	90.00%	$ 242	$ 200	$ 20	$ 8	$ 6
5.00%	95.00%	400	332	32	16	10
2.00%	98.00%	674	552	50	33	18
1.00%	99.00%	986	820	66	55	29
0.96%	99.04%	1,004	831	68	58	29
0.40%	99.60%	1,464	1,180	92	95	43
0.39%	99.61%	1,496	1,216	93	95	43
0.20%	99.80%	1,845	1,555	119	138	61
0.10%	99.90%	2,507	1,962	157	184	90

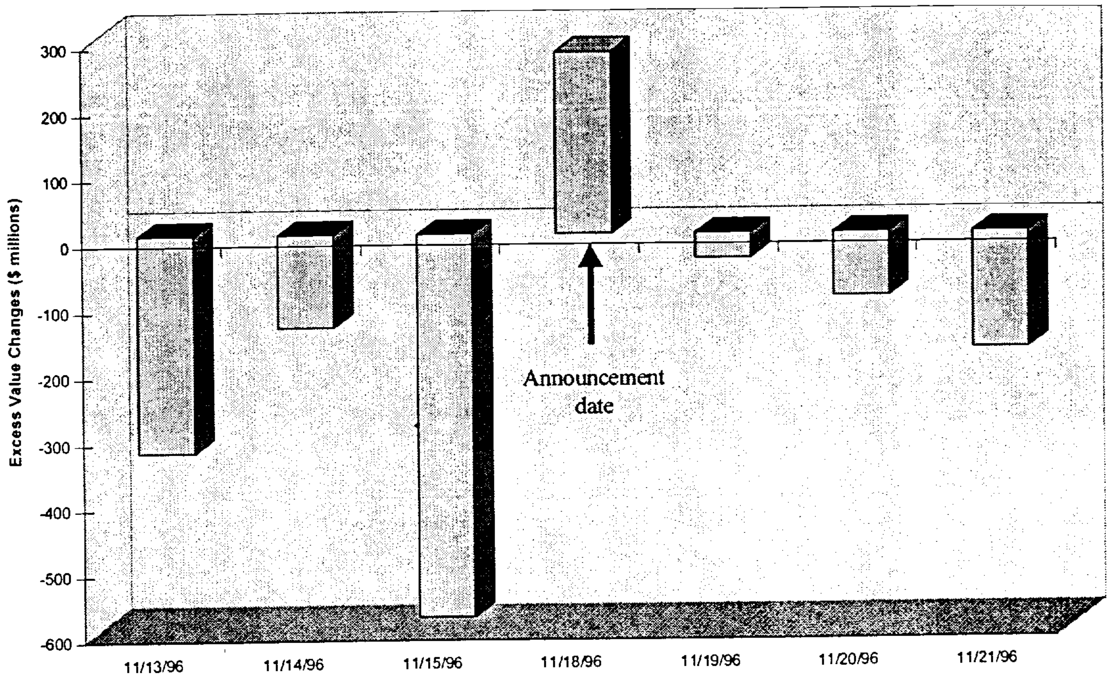
Graph of Above Data ($mm)



[45] Source: USAA

[46] "1-P" in column two and on the graph's y-axis represents the annual probability that a catastrophic loss suffered by USAA will be less than the corresponding amount shown in column three and on the x-axis.

Figure 4 Changes in Berkshire Hathaway's Market Value (in excess of the market)



Notes: Graph shows the value of the percentage excess return of Berkshire Hathaway's market capitalization in excess of the S&P 500. Announcement date is the first day on which news of National Indemnity's reinsurance contract with the California Earthquake Authority is reflected in the closing stock price.

Table 2 Residential Reinsurance Transaction Comparison

Issue	1999	1998	1997
Exceedence Loss	$1.0 billion	$1.0 billion	$1.0 billion
Exhaustion Loss	$1.5 billion	$1.5 billion	$1.5 billion
Risk Capital	$200 million	$450 million	$400 million
Premium	3.66%	4.13%	5.76%
Expected Loss	0.44%	0.52%	0.63%
Premium / Expected Loss	8.3	7.9	9.1
Attachment Probability	0.76%	0.87%	0.96%
Exhaustion Probability	0.26%	0.32%	0.42%
USAA Coinsurance	10%	10%	20%
Coverage Period	52 weeks	50 weeks	52 weeks
Extended Claims Period	6 months	6 months	6 months
Defeasance Period	not applicable	not applicable	10 years
Interest Payments	Quarterly	Quarterly	Monthly
S&P Rating	BB	BB	BB

Source: Residential Re Offering Memoranda.

Table 3 Effect of AIR Model Updates on USAA Expected Losses

(a)

Estimated Annual Occurrence Losses ($ millions)
(12/31/98 exposure, no demand surge included)

Estimated Probability Of Occurrence	**1997 Model**	**1999 Model**	**% Change in Losses**
200 basis points	$600	$564	-5.9%
100 basis points	$831	$751	-9.7%
40 basis points	1,239	1,066	-14.0%
20 basis points	1,431	1,377	-3.8%
10 basis points	1,776	1,603	-9.8%

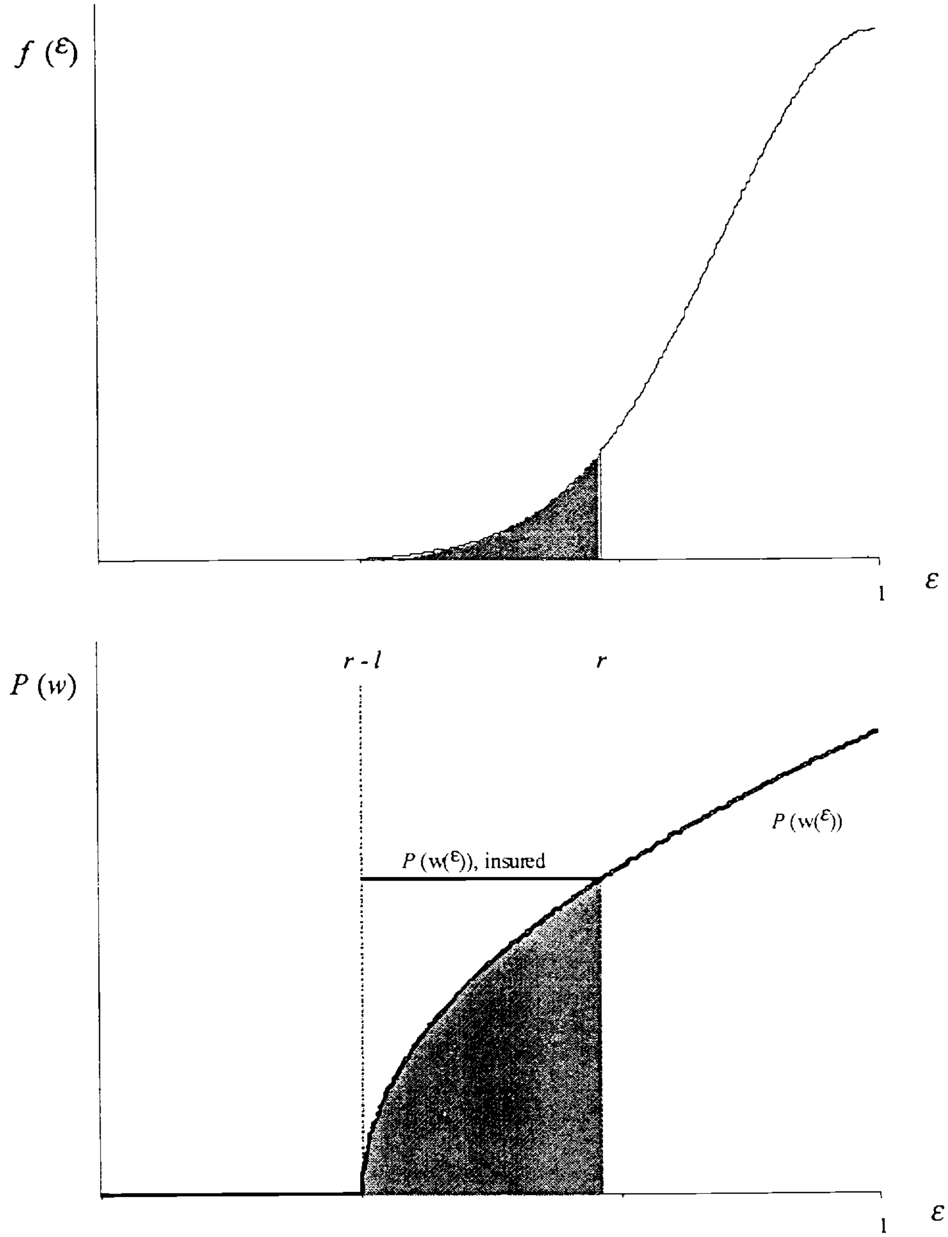
(b)

Effect of Demand Surge Changes
Estimated Annual Occurrence Losses ($millions)
(12/31/98 exposures, 1999 models)

Estimated Probability Of Occurrence	**Using 1997 Demand Surge Function**	**Using 1999 Demand Surge Function**	**% Change in Losses Due to Changes in Demand Surge**
200 basis points	654	641	-2.0%
100 basis points	868	849	-2.2%
40 basis points	1,283	1,240	-3.4%
20 basis points	1,689	1,633	-3.3%
10 basis points	2,039	1,962	-3.7%

Source: Residential Re Offering Memorandum, May 1999.

Figure 5 Optimal Constrained Hedging Program Under The Froot, Scharfstein, And Stein (1993) Model



Note: Shaded region indicates the area in which a company would hedge, if given the choice of range over which it could fully insure against losses at fair value.

Figure 6 Percentage of Exposure that Insurance Companies Reinsure (by various event sizes)

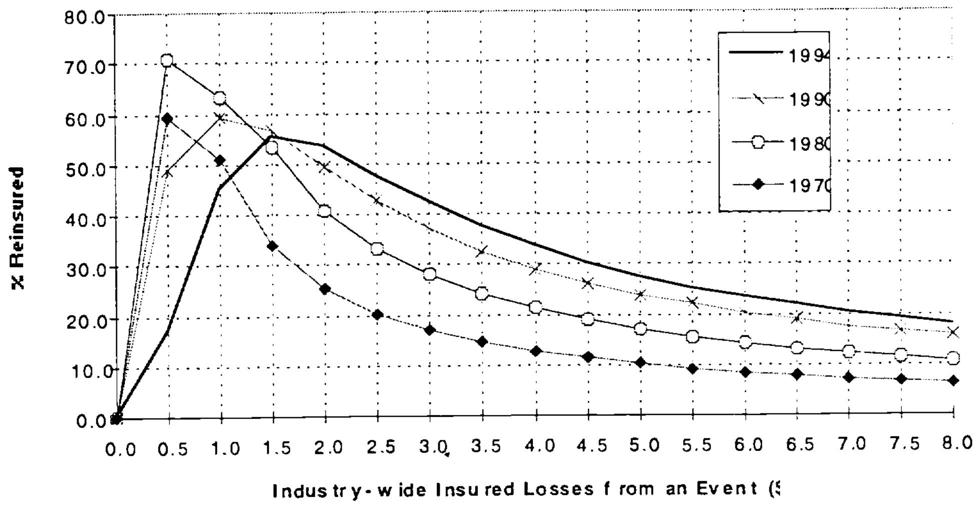


Figure 7 Price level of reinsurance contracts relative to actuarial value, 1989-1998

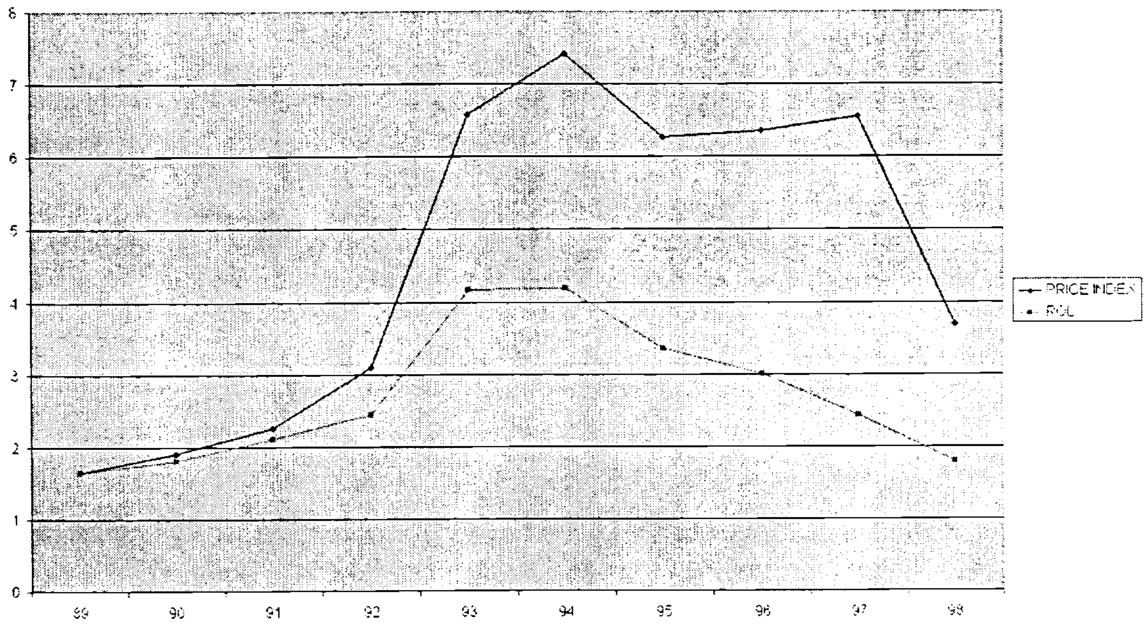


Figure 8 Premium To Expected Loss, By Exceedence Probability And Year

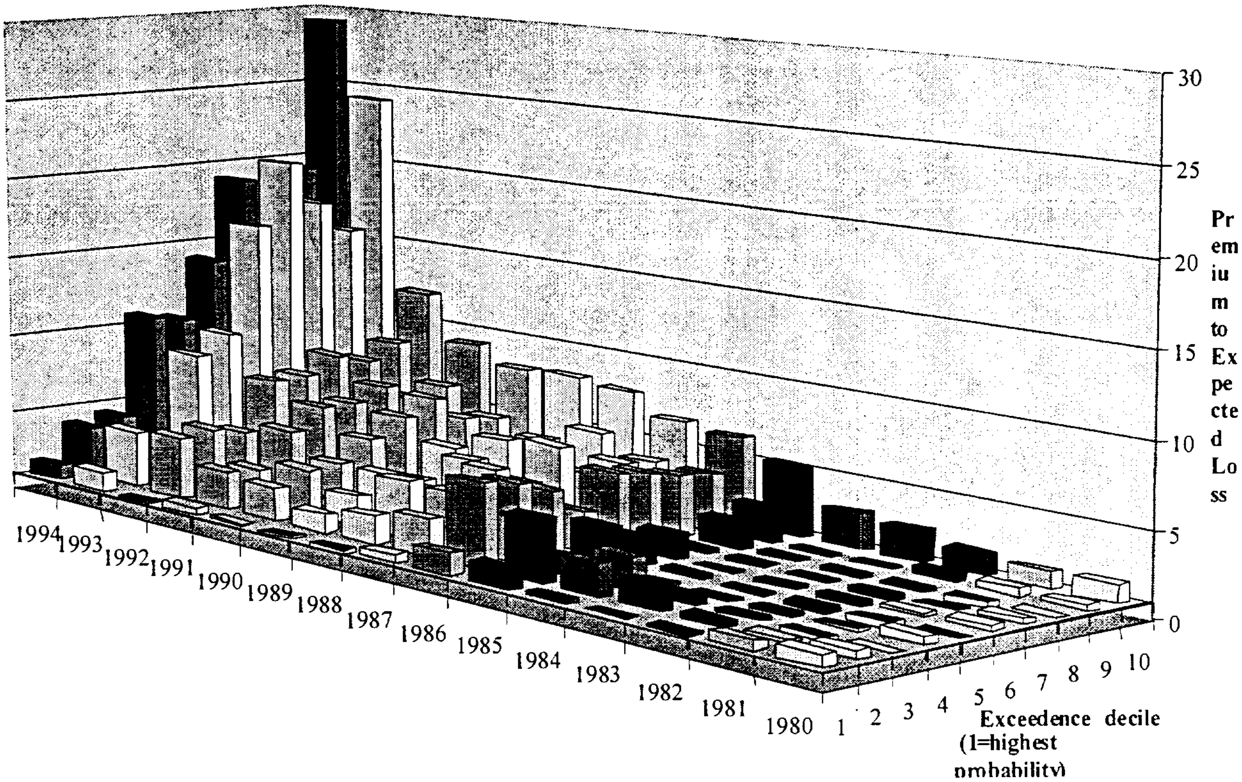


Table 4 Changes In Reinsurance Premiums And Quantities Purchased Subsequent To Hurricane Andrew

	(a) Southeast exposure			(b) Hurricane exposure		
	Mean exposure	Mean $\Delta\ln(p_{j,t})$	Mean $\Delta\ln(q_{j,t})$	Mean exposure	Mean $\Delta\ln(p_{j,t})$	Mean $\Delta\ln(q_{j,t})$
5 most-exposed insurers	0.141	0.415	-0.021	0.184	0.583	-0.082
5 least-exposed insurers	0.000	0.335	-0.013	0.112	0.336	-0.047

Comparison of price responses in the year after Hurricane Andrew (8/20/92–8/19/93) for different insurers. Panel (a) contrasts insurers that have high and low exposure to the Southeast (as measured by market share). Panel (b) contrasts insurers that have high and low exposure to hurricanes. The table shows the mean exposure and the mean price change of the 5 most extreme contracts in each case. The mean price change for the insurers with lesser exposure to the Southeast is calculated using all 14 of the insurers that have zero market share in that region.