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The allocation of catastrophe risk

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Abstract

The potential losses from catastrophes have led financial researchers to address the following questions: (1) to what extent is catastrophe risk being shared (insured) and is the allocation of catastrophe risk consistent with notions of optimal risk sharing? (2) if not, what market imperfections hinder the efficient allocation of catastrophe risk? and (3) are there government policies or private market solutions that could lead to a more efficient allocation of catastrophe risk? This paper summarizes the research that has been conducted on these questions. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Both Hurricane Andrew in 1992 and the Northridge earthquake in 1994 caused insured losses in excess of $12 billion. While the magnitude of these losses was unprecedented, the losses were small compared to the potential losses that could result if a major storm or earthquake hit a more developed area. For example, modelers estimate that insured losses would exceed $75

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billion if a hurricane like Andrew were to hit Miami, Florida. Similar estimates exist for an earthquake in San Francisco. [1]

The potential losses from catastrophes have led financial researchers to address the following questions: (1) to what extent is catastrophe risk being shared (insured) and is the allocation of catastrophe risk consistent with notions of optimal risk sharing? (2) if not, what market imperfections hinder the efficient allocation of catastrophe risk? and (3) are there government policies or private market solutions that could lead to a more efficient allocation of catastrophe risk? The purpose of this paper is to summarize the research that has been conducted on these questions.

To the extent that catastrophe risk is shared, it usually occurs in two steps. First, individuals and businesses purchase insurance coverage from primary insurers. Second, primary insurers purchase reinsurance from reinsurers that typically operate worldwide. In this way, catastrophe risk is shared around the globe. The evidence, however, indicates that (a) a large amount of catastrophe risk is retained by individuals and businesses and (b) when it is insured, most of the risk is retained by the primary insurer instead of being reinsured (Froot, 1999, 2000).

If insurers and reinsurers do not completely diversify catastrophe risk (which of course is never the case), these institutions need to hold capital to bond their promises to pay catastrophe claims. The providers of this capital, usually equityholders, therefore ultimately bear a substantial amount of catastrophe risk. If the amount of capital held by insurers and reinsurers is insufficient to pay potential catastrophe claims, then some of the catastrophe risk falls back on either policyholders of these insurers, policyholders of other insurers via state insolvency funds, or taxpayers via disaster assistance. [2]

Cummins et al.'s (2002) article, which is included in this issue, provides an innovative and detailed analysis of the ability of insurers to pay catastrophe losses. Their analysis indicates that insurers' ability to pay promised catastrophe claims has improved substantially over the course of the 1990s, and that as of 1998 the vast majority of catastrophe claims from a mega-catastrophe in the US (about $100 billion in insured losses) would be paid by insurers. Although most claims will be paid, they highlight that there would still be billions of dollars in unpaid claims, a large number of insurer insolvencies, and a severe disruption in insurance markets following a mega-catastrophe.

[1] Note that these estimates are for insured losses. Uninsured losses also would be substantial, especially for earthquakes.

[2] All states in the US have insolvency funds that pay policyholder claims of insolvent insurers up to a limit. See Arvan and Nickerson (1998) for a recent analysis of the interactions between disaster assistance and private insurance markets.

Concern about the ability of insurers to pay promised catastrophe claims has led to a number of private market responses, as well as public policy proposals. Private responses include financial innovations, such as catastrophe options and catastrophe bonds. Public policy responses include proposals for allowing insurers to establish tax-deferred catastrophe reserves and proposals for state and federal government reinsurance programs.

This paper proceeds as follows. Since the financial innovations and public policy proposals related to catastrophe risk are largely motivated by the assumption that insurers are not prepared to pay catastrophe claims from a major event, I first review the contribution and conclusions from the Cummins et al. paper in Section 2. In Section 3, I identify potential explanations for the credit risk associated with catastrophe insurance. In Section 4, I discuss how financial innovations, such as catastrophe options, potentially reduce contracting costs relative to traditional reinsurance contracts. The main disadvantage of these new contracts – basis risk – is also discussed. Also in Section 4, I briefly discuss the main advantages of catastrophe bonds over equity capital and reinsurance. In Section 5, proposals for government reinsurance programs and tax-deferred catastrophe reserves are briefly discussed. The paper ends with a short summary.

2. Can insurers pay for the big one?

Concerns about whether insurers could pay claims arising from a mega-catastrophe were heightened following hurricane Andrew and the Northridge earthquake. The consensus among analysts in 1994 was that the insurance industry was undercapitalized, especially insurers with significant catastrophe exposure. At year-end 1994, total capital of US property and liability insurers was less $200 billion (A.M. Best Company, 1995). The majority of this capital was held by insurers without catastrophe exposures. Also, some of the capital held by insurers with catastrophe exposures could have been needed to pay unexpected claims from non-catastrophe related lines of business. Consequently, the industry appeared to be undercapitalized, i.e., there would be many unpaid claims and numerous insolvencies if a mega-catastrophe occurred (see Insurance Services Office, 1996).

In response to the apparent lack of capital and the high prices for catastrophe reinsurance in the mid-1990s, there was a large influx of capital, especially for catastrophe reinsurers located in Bermuda. Because of the inflow of new capital and the lack of a major catastrophe, the capital of the property–liability insurance industry grew steadily during the latter part of the 1990s. By 1999, US property–liability insurers' capital was over $300 billion. [3]

[3] Interestingly, a common question asked in 2000 was "Is the industry overcapitalized?"

A "back-of-the-envelope" calculation of the ability of insurers/reinsurers to pay catastrophe claims would simply compare industry capital to potential claims. This simple approach, however, can be misleading because insurers have different exposures to catastrophe risk and different amounts of capital. Cummins et al. (2002) present an innovative analysis that takes these considerations into account. Their reference point is the allocation of catastrophe risk among insurers/reinsurers in a perfect reinsurance market. In a perfect market, catastrophe risk would be diversified across insurers/reinsurers to the greatest extent possible, and whatever non-diversifiable catastrophe risk that remained after optimal diversification would be shared across insurers in proportion to their ability to bear this risk. In this setting, each insurer would be responsible for paying a share of the aggregate outcome of catastrophe claims, and the industry would act like a single entity when it comes to paying catastrophe claims. Of course, the actual allocation of catastrophe risk deviates from this ideal, and Cummins et al. provide estimates of the difference between the ideal outcome and what would be expected in practice.

To explain their method, suppose that the amount of capital held by insurer i equals Q_i and fix a realization for the industry's total loss at L. [4] The distribution of L across insurers determines how much of L could be paid. For example, one possible distribution of L might result in 100% of L being paid, because the amount distributed to each insurer is less than each insurer's capital, Q_i. Another possible distribution of L across insurers could result in 70% of L being paid. To find the *expected* amount that could be paid conditional on L, the authors assume that insurer losses are jointly normally distributed (or alternatively, jointly lognormally distributed). They then calculate the conditional expectation of how much insurer i would be able to pay conditional on L and insurer i's capital, Q_i. They sum these conditional expectations to get an expression for the expected amount of total paid losses conditional on industry losses, which they call the response function.

The response function depends on the parameters of the underlying probability distribution. For example, for the normal distribution assumption, the response function depends on each individual insurer's mean loss, its standard deviation of losses, and its correlation coefficient with industry losses. These parameters are estimated for a sample of insurers with complete data over a 15-year period. The estimated parameters are then "applied" to insurers without complete data based on regressions that relate the parameters to underlying firm characteristics. Once parameters for all insurers are estimated, the authors calculate the response function for a given industry loss L and then vary L across a reasonable range.

[4] If the risk were allocated efficiently in a perfect market, then the industry would be able to pay the minimum of L and total industry capital, $\sum Q_i$.

The results indicate that the ability of insurers to pay catastrophe claims increased substantially over the 1990s. For example, using one set of parameters, in 1991 insurers would have been expected to pay about 80% of the claims from a $100 billion loss, compared to about 93% in 1997. The relatively high proportion of claims that would be expected to be paid at the end of the decade might suggest that the industry is sufficiently capitalized. Several points, however, are worth noting when interpreting this result.

First, Cummins et al.'s analysis provides estimates of the expected value of the distribution of actual payments. The actual percentage of claims that the industry would pay for a given catastrophe could be lower than the 93% reported for 1997. As an extension to their analysis, it would be informative to have confidence intervals around the expected payment estimates. For example, conclusions about the adequacy of insurer capital could differ if the lower bound of a 90% confidence interval (around the 93% point estimate) were 85% versus 60%.

Second, as noted by the authors, even if 93% of catastrophe claims were paid by insurers, there would still be billions of dollars in unpaid claims and a large number of insurer insolvencies. Some of the policyholders of these insolvent insurers would receive payments from state insolvency funds and from disaster assistance, but some policyholders would experience considerable financial hardship, even though presumably they had thought that they had insured against such a contingency. In addition, the shock to industry capital following a mega-catastrophe would disrupt property insurance markets and perhaps other insurance markets. [5]

In conclusion, Cummins et al.'s analysis indicates that the industry is in a much better position to pay catastrophe claims than a decade ago. However, a mega-catastrophe would still leave billions of dollars of unpaid claims and significantly disrupt insurance markets.

3. Market imperfections affecting insurers' ability to pay catastrophe claims

Insurers and reinsurers's limited ability to pay catastrophe claims arises because of limited diversification of catastrophe risk and/or limited capital. In this Section, I identify the market imperfections that limit insurer diversification and insurer capital.

As is true with most types of insurance, moral hazard and adverse selection problems limit the extent to which insurers trade and therefore diversify catastrophe risk. Moral hazard exists with regard to the selection of policies

[5] See Harrington and Niehaus (2000b) for a review of the theoretical and empirical literature on short-run disruptions in insurance markets.

underwritten by the primary insurer and with regard to claims processing. Various methods are used to mitigate these problems, including costly monitoring by reinsurers (both ex ante and ex post) and incomplete risk sharing of catastrophe risk (i.e. the use of deductibles, coinsurance, and limits). [6]

To the extent that catastrophe risk cannot be or is not diversified (due to contracting problems), insurers and reinsurers need to hold capital to make their promises to pay catastrophe claims credible. The benefits of additional capital include higher prices for policies (Doherty and Tinic, 1981), greater protection of franchise value (Cagle and Harrington, 1995), and a reduction in foregone investment opportunities (Froot and Stein, 1998). However, the additional agency and tax costs associated with holding more capital limit the amount of capital held by insurers. [7] In addition to moral hazard and adverse selection problems in the reinsurance market and tax and agency costs of holding capital, Froot (2000) presents other explanations for the limited sharing of catastrophe risk. These explanations include behavioral explanations, market power on the part of reinsurers, and price regulation at the state level.

4. Financial innovations

Several innovative financial contracts were introduced in the 1990s, which were intended to enhance the ability of insurers to manage their catastrophe risk.

4.1. Catastrophe derivatives

In 1992, the Chicago Board of Trade (CBOT) introduced catastrophe futures contracts that were based on an index of underwriting losses experienced by a large pool of property insurance policies written by 22 insurers. The CBOT constructed a national index, as well as three regional indices. If a catastrophe occurred, presumably the pool of policies would experience a large

[6] See Niehaus and Mann (1992) for a discussion of these issues. Interestingly, computer models that simulate hurricanes and earthquakes and estimate property damage based on information about the location of buildings might give market participants more objective measures catastrophe exposures and therefore facilitate the trading of catastrophe risk.

[7] See Jaffe and Russell (1997) and Harrington et al. (1995). Harrington and Niehaus (2000a) show that the tax costs are especially pronounced for high layers of catastrophe reinsurance coverage. The opaqueness of insurer operations also implies that managers of insurers are likely to have better information about the assets in place and growth opportunities than outside investors, which suggests that the adverse selection problem highlighted by Myers and Majluf (1984) also makes raising new capital costly for insurers and therefore limits the amount of capital that they hold.

loss, which would cause the underlying index to increase. A long futures position therefore could be used by an insurer to hedge against catastrophe risk.

The primary advantage of catastrophe derivatives arises because the payoffs are based on an index that, for the most part, cannot be influenced by the actions of market participants. In contrast, reinsurance contracts typically are based on the primary insurer's losses, which as noted above leads to moral hazard and adverse selection problems. Niehaus and Mann (1992) argue that catastrophe derivatives therefore should involve lower transaction costs (since less monitoring is needed) and more complete shifting of aggregate risk (since risk-sharing is not needed to control incentive conflicts). [8]

These contracting advantages, however, come at a cost – the payoffs on catastrophe derivatives are based on industry-wide losses, not a specific insurer's loss, which implies that there is basis risk. Indeed, basis risk was one of the main criticisms of the CBOT's original catastrophe futures contracts. Another criticism was that the symmetric payoffs from the futures contracts deviated from the asymmetric (option-like) payoffs common with reinsurance contracts. Not only was the symmetric payoff not familiar to reinsurance market participants, it raised the concern that the unlimited downside risk associated with a short position created a credit risk problem despite the CBOT's margin and daily settlement arrangements. Concerns also were raised about the possibility that the payoffs on the futures contracts could be manipulated by one of the insurers whose policies determined the underlying index.

To remedy the problems, the CBOT replaced the futures contracts in 1994 with catastrophe options based on an index determined by Property Claims Service's estimates of insured property damages. In addition, the CBOT introduced contracts for more narrowly defined geographical regions, as well as state contracts for Florida and California. To resemble reinsurance contracts and to limit credit risk, the option contracts are marketed and traded as call spreads (a long call position is combined with a short call at a higher exercise price). If the settlement value of the index falls in the region between the exercise prices of the two options, then the purchaser would receive a positive payoff. Thus, purchasing a catastrophe call spread is similar to purchasing a layer of reinsurance coverage.

Six years after their introduction, trading volume in catastrophe options remains modest. One potential explanation is that, despite the smaller geographical regions for the underlying indices, the new contracts still have considerable basis risk. However, several papers have examined the basis risk

[8] Another potential advantage is that the market structure (margins and marking to market) of exchange-traded derivatives can lead to a more liquid market for trading catastrophe risk. Whether there is demand for this liquidity by insurers is uncertain. See Niehaus and Mann (1992) for a discussion of liquidity issues.

associated with catastrophe derivative contracts and have concluded that the basis risk associated with derivative contracts based on state-specific indices is not large. For example, Harrington and Niehaus (1999) use time series data on insurer by-line underwriting results and PCS estimates of catastrophe losses to measure the hedging effectiveness of regional and state-specific catastrophe derivative contracts. Their evidence indicates that state-specific derivative contracts would provide effective hedges for most large insurers. Cummins et al. (2000) use simulated catastrophe data and extensive information on insurers' exposure to catastrophes in Florida to assess basis risk with catastrophe options based on a statewide Florida index of catastrophe losses. Their evidence suggests that the statewide contract would provide an effective hedge for a high proportion of Florida's total catastrophe exposure. [9]

Thus, based on the existing research, basis risk does not appear to be the main impediment to the use of catastrophe options. Another potential explanation is that during the latter part of the 1990s catastrophe reinsurance prices declined and that insurers view traditional catastrophe reinsurance as having a lower price than catastrophe options. Another potential impediment to catastrophe derivatives is their statutory accounting treatment, which does not recognize them as increasing surplus (capital).

4.2. Catastrophe bonds

Several capital market instruments have been developed in the past decade to enhance insurers' ability to manage catastrophe risk. One innovation has been catastrophe-contingent equity and debt securities, whereby insurers prearrange to issue equity or debt if a catastrophe occurs. The more commonly used capital market innovation, however, has been catastrophe bonds. [10] With these securities, investors agree to forgive some of the principal and/or interest payments on a debt instrument if a specified catastrophe occurs. If a catastrophe does not occur, then investors receive their principal plus a coupon that typically is well above LIBOR (Froot, 1999, 2000). [11]

[9] Major (1999) uses simulated catastrophe data to examine the basis risk that would be associated with derivative contracts based on zip code indices. Not surprising, he concludes that zip code contracts would have lower basis risk than state-specific contracts. Of course, there also are disadvantages of creating a plethora of contracts (e.g., based on losses at the zip code level) that can be combined by individual insurers to meet the hedging needs of their specific book of business. The Bermuda Commodities exchange offered zip code based catastrophe derivative contracts for a short period of time, but there appeared to be a lack of demand.

[10] Between 1995 and 2000, there were about 40 catastrophe bond issues.

[11] For example, USAA's 1997 catastrophe bonds promised a yield of 576 basis points above LIBOR; in 1998 the yield dropped to 416 points above LIBOR.

Catastrophe bonds offer several potential advantages over alternative methods for insurers to deal with catastrophe risk, such as reinsurance and equity capital. Relative to traditional reinsurance, catastrophe bonds have less credit risk because the total amount of funds which can be called by the insurer if a catastrophe occurs are placed in trust. In contrast, reinsurers do not hold funds equal to their maximum exposure, and thus reinsurers have insolvency risk. However, if holding capital in trust is costly, then backing primary insurers' catastrophe exposures solely through catastrophe bonds would be inefficient, because the arrangements would not take advantage of diversification.

Just as debt financing in general has a tax advantage relative to equity financing, catastrophe bonds involve lower tax costs than equity capital. Additional debt financing generally involves greater financial distress costs. The catastrophe bond structure, however, reduces financial distress costs relative to traditional subordinated debt, because the contingent payments are based on readily observable variables (the occurrence of a catastrophe) and the payments are agreed upon ex ante. Catastrophe bonds also reduce agency costs relative to equity capital, because the funds raised from the bond issue are placed in trust and cannot be used by managers unless a specified catastrophe occurs.

In summary, catastrophe bonds provide advantages over reinsurance and equity capital, which should improve insurers' ability to manage their catastrophe risk. The use of catastrophe bonds, however, is hindered by regulatory constraints that generally require that the bonds be issued by an offshore special purpose vehicle. As a result, catastrophe bonds can involve substantial transactions costs. While the use of catastrophe bonds is not widespread, Froot (2000) suggests that their impact could be much greater than their actual use, because they provide competition for traditional catastrophe reinsurance and thereby affect reinsurance prices.

5. Public policy proposals

Concerns about the ability of private insurers to pay catastrophe claims have led to a number of proposals for government catastrophe insurance/reinsurance programs. [12] The underlying economic rationale for government insurance/reinsurance of catastrophe risk rests on the notions that catastrophe risk cannot be diversified cross-sectionally and therefore needs to be diversified over time,

[12] Three states, California, Florida, and Hawaii have established insurance or reinsurance plans for catastrophe coverage, and proposals for a federal catastrophe reinsurance program have been introduced in Congress. Under one plan (The Homeowners Insurance Availability Act of 1999, HR 21), the government would sell high-layers of catastrophe reinsurance using an auction mechanism. To mitigate moral hazard and adverse selection problems, the program would include partial coverage (coinsurance) and have payoffs tied to regional losses.

and that governments can enforce inter-temporal risk sharing arrangements more efficiently than private parties. Inter-temporal risk sharing arrangements naturally involve transferring resources across time. If a government has the ability to borrow at lower rates than private entities (due to lower credit risk, which arises from their ability to tax), then that government might be able to arrange inter-temporal risk sharing more efficiently than private parties (Lewis and Murdock, 1996). Of course, there are also potential inefficiencies with government insurance programs. In addition, to operating efficiency issues, government insurance programs often respond to political pressure and lower rates for certain groups, which in turn distorts loss control incentives.

An alternative to government reinsurance would be to address the source of the market failure for high layers of catastrophe reinsurance coverage. If the main reason that private reinsurance for high layers of catastrophe coverage does not exist is because of the high tax costs associated with holding the capital necessary to make such insurance credible, then an alternative policy is to reduce the tax costs associated with holding capital. One proposal, The Policyholder Disaster Protection Act (HR 2749), would allow insurers to make tax-deductible contributions from premium income to a special reserve for catastrophe-related lines. [13]

6. Summary and other research issues

The catastrophe losses during the 1990s and the estimates of potential future catastrophe losses have led to a number of interesting developments, including

- the development of more sophisticated catastrophe models to measure catastrophe exposures,
- an increase in capital supporting catastrophe insurance/reinsurance, especially in tax-advantaged locations,
- the development of catastrophe bonds,
- the trading of catastrophe options.

All of these developments can be viewed as attempts to provide more capital and to lower the cost of capital backing catastrophe exposures. The impact of these developments vary. The first two developments listed (catastrophe models and the increase in capital) certainly have had an important impact on the markets that allocate catastrophe risk. Catastrophe exposures are better understood and the market's capacity to bear catastrophe risk has increased

[13] See Harrington and Niehaus (2001) for a discussion of the advantages and disadvantages of tax-deferred reserves versus other public policies, such as reinsurance programs.

(Cummins et al., 2002). The impact of catastrophe bonds is uncertain – they are used relatively infrequently, but they do provide competition for traditional reinsurance (Froot, 2000). To date, the impact of catastrophe options has been minimal.

Perhaps the most important development is the application of financial concepts and tools to the management of catastrophe risk. Previously, catastrophe risk was an issue for specialists in insurance and reinsurance. Now, investment bankers, derivatives exchanges, and fund managers are interested in catastrophe risk. Catastrophe risk is increasingly being viewed as another asset class (Litzenberger et al., 1996).

An unresolved issue is the pricing of catastrophe risk in a portfolio context. The common assumption in the literature is that catastrophe risk is essentially a zero-beta risk, i.e., catastrophe losses are not correlated with returns on other assets. While historical data over the past 50 years are consistent with this assumption (Froot and Seasholes, 1997), the "really big one" has not occurred. If a hurricane causes \$100 billion in insured losses or an earthquake causes total losses (insured and uninsured) of \$150 billion in California, will financial markets be disrupted? And if so, for how long? The answers to these questions affect whether market participants really view catastrophe risk as a zero-beta risk, and therefore require no risk premium for investing a small proportion of their wealth in securities with payoffs that depend on catastrophe losses. Hopefully, the answer to these questions will be provided by theoretical models, as opposed to empirical observations.

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