Extreme Events and the Market for Terrorist Insurance

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Abstract

Why do markets which insure against low frequency/high cost events frequently

suffer disruption following the occurrence of such an event? This paper examines

several possible reasons and discusses the implications for public policy.

Revised Draft: January 11, 2001.

For presentation to NBER Insurance Conference, February 2002.

1. **Introduction**

The events of September 11, 2001 are likely to lead to insured losses in excess of $50 billion, making it not just a massive human tragedy but also the largest single insured loss in history. The ability of the insurance industry (both primary insurers and re-insurers) to meet the resulting claims is not in doubt. At this time, the combined reserves of the property casualty insurance industry in the US alone exceed $300 billion, and many claims will fall on the reserves of life insurance and workers' compensation carriers as well as re-insurers located outside the US. [1]

For the industry, the major questions raised by the attack all relate to the structure of the market going forward. Already a number of firms have reacted to the event by raising prices, canceling policies, placing limits on coverage, or even withdrawing from the terrorist insurance line altogether. Since terrorism insurance is a requirement in many industries, for example office building construction and airline transportation, the collapse of the terrorism insurance market has precipitated a demand for alternative risk sharing arrangements. Foremost among these are proposals for the federal government to provide some form of insurance of last resort.

Drawing on our previous research on the operation of catastrophe insurance markets, Jaffee and Russell [1997], this paper seeks to answer two basic questions.

1) Why did the terrorist insurance market collapse so abruptly?

2) What is the best public policy response to what we will show is a recurring problem, the failure of insurance markets following the occurrence of an extreme event?

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[1] It is possible that financial difficulties may be felt by some Lloyd's syndicates. Lloyd's provided sleep-easy (top layer) coverage on the World Trade Center with reinsurance from Swiss Re. Current estimates put Lloyd's total exposure at 12% of their capacity, well above their worst planning scenario (a loss of 10% of their total capacity). See James Moore, "Insurance Story," The Times, 1 Oct. 2001.

2. Terrorist Insurance Market Failure: Some Preliminary Issues

Whenever insurance markets are compromised, it is common to look for one or other of the related problems of moral hazard and adverse selection. In the case of insurance against terrorist acts, however, it seems unlikely that either of these market imperfections plays a major role. It is true that about 20% ($10 billion) of insured losses are business interruption costs, and these are probably subject to some ex post moral hazard due to the difficulty of determining what fraction of losses would have occurred anyway in an accelerating business cycle downturn. But the market failure extends well beyond the failure of the market for business loss insurance.

In particular, it is difficult to see how asymmetric information between the insurance companies and the policy holders with respect to future terrorist acts can lead to adverse selection here. Moreover, in the case of general terrorist insurance, it seems unlikely that purchasers of insurance will fail to take precautions against loss when so many lives are at stake (including their own). This is especially true given that the failure to take precautions would be readily apparent to their employees and customers.

Without these standard issues of asymmetric information, however, it is not immediately clear why the market fails to clear. For example, we can readily grant that the likelihood of future terrorist attacks was higher after September 11 than before, but this simply calls for higher premiums. Alternatively, we may assume that the degree of uncertainty surrounding terrorism went up, either increasing the variance of claims or increasing parameter uncertainty, but again this could be handled by an appropriate adjustment in the price. What is hard to understand is for example the reaction of the insurers of Chicago's airports. Prior to the event, Chicago carried $750 million of terrorist insurance for an annual premium of $125,000. Post September 11, their

insurers would only offer $150 million of coverage for the new premium of $6.9 million. Even if the increase in premium is understandable, why was the quantity so severely rationed? [2]

In view of the observed rationing of catastrophe and terrorist insurance, it is natural to ask whether terrorism or catastrophe insurance is different from ordinary casualty lines, such as auto insurance. It is clear that governments do behave as if some lines of insurance present difficulties for private markets. For example, the US government already provides insurance against (among other risks) catastrophic nuclear accidents, political risks in overseas trade, riots, floods, bank runs, and marine and aviation war risks; see Government Accounting Office (GAO) [2001] and Moss [forthcoming]. Moreover, in those countries which were exposed to terrorist attacks earlier, including Northern Ireland, Great Britain, and Israel, terrorism insurance is uniformly provided by the government; see Appendix 1. Similarly, the states of California and Florida have actively intervened in the markets for earthquake and hurricane insurance respectively; see Appendix 2.

Although the fact of government provision in these lines of insurance is not in dispute, the exact reason for state provision is far from clear. On terrorism insurance, for example, the GAO states:

> "It seems clear, given insurers' increased recognition of their exposures in the aftermath of the unprecedented events on Sept. 11 2001, that coverage for terrorist acts is not now amenable to normal insurance underwriting, risk management, and actuarial techniques. As a result insurers and re-insurers are concerned about their ability to set an appropriate price for insurance coverage for terrorist acts. Given this uncertainty if this kind of insurance were to be offered at all, it is likely that either the price insurers set would be prohibitively high or so low as to invite insolvency."

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[2] The primary carriers of insurance might answer that the quantity of insurance was rationed because reinsurance was not available. That merely pushes the question one step back.

Pricing terrorism risk is certainly not a simple task, but neither is pricing say commercial satellite risk, and this is done at Lloyd's on a nod and a handshake. Moreover we can find no reference in the literature to lines requiring "normal" actuarial techniques versus any other techniques. The California Earthquake Authority, for example, is required by law to set premiums on an actuarial basis, a task for which they are certainly no more qualified than private insurers. The next section revisits the primitives of insurance theory to try to understand why insurance firms may operate differently across lines.

3. Risk Bearing and Insurance: Is Terrorism Insurance Different?

As noted by Samuelson [1963] , the essence of insurance is the subdividing, not the pooling of risk. In the context of insurance firms, subdividing refers to the allocation of a given portfolio of risks among a large number of shareholders. Pooling refers to the creation of a portfolio consisting of a larger number of individual risks. It is normally the case that insurers, whether they are organized as mutuals or as joint stock companies, in fact do pool risks. This sets up a tension between pooling and subdividing, a tension made clear by Ross [1999]:

> "After all, when an insurance company or a "swaps shop" opens its doors, it attracts n independent risks, it does not cut up some larger existing risk. The presumption is that the race between a financial market which cuts up risks and a business that adds them is won by the market..."

In this section we provide a simple model of the insurance firm which is designed to capture the essence of the pooling/subdividing issue. The model is designed to shed light on the fundamental question of whether or not the terrorism (extreme event) line of insurance is of its nature any different from the standard property casualty line. The point of view is that of the potential investor in an insurance syndicate.

Insurance Portfolio Investment Decisions

We start by reviewing the statistical properties of an insurance portfolio based on the characteristics of the underlying risks. To formalize this argument, we apply a mean-variance analysis to a group of identical generic risks $\tilde{X}_i$—later we will apply the results to specific insurance lines—where for each risk the annual expected loss is E_i and the annual variance is V_i. A special case is one in which each potential investor them self is exposed to the risk in which case if they fail to join a syndicate they self insure at an expected cost of E_i with a variance of V_i. For simplicity, we are assuming the parameters E_i and V_i are known with certainty.[3]

Now suppose that an insurance company considers creating a portfolio of M such risks, on which it charges each customer a premium P. We denote the policy loading, $P – E_i$, as ε, which we assume to be positive. The correlation coefficient r, $-1 \leq r \leq 1$, is the same between each pair of risks. Finally, assume that the insurance company has N shareholders, each holding an equal stake in the firm.[4] This means that each shareholder will own a share of the insurance portfolio α, $\alpha = 1/N$.

The expected portfolio income per shareholder E and the portfolio variance per shareholder V for the insurance firm can then be written as (exp and var are the expected value and variance operators respectively):

$$(1a) \quad E = \textit{Expected portfolio income} = \exp\left[\textbf{\textit{a}}\left(MP - (\tilde{X}_1 + \tilde{X}_2 + ...\tilde{X}_M)\right)\right] = \textbf{\textit{a}}M(P - E_i) = \textbf{\textit{a}}M\textbf{\textit{e}},$$

$$(1b) \quad V = \textit{Portfolio Variance} = \text{var}\left[\textbf{\textit{a}}\left(\tilde{X}_1 + \tilde{X}_2 + ...\tilde{X}_M\right)\right] = \textbf{\textit{a}}^2\{(1 - \textbf{\textit{r}})M + \textbf{\textit{r}}M^2\}V_i.$$

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[3] There is a large literature dealing with the effects of parameter uncertainty on model predictions. Generally speaking, these effects are found to be relative small. See, for example, Froot [2001].

[4] In the case of a mutual insurance firm, the policyholders and shareholders would be one and the same, and M = N.

It is apparent by inspection of equation (1) that the expected income E and variance V for the portfolio depend on the parameters α, M, ε, ρ, and V_i in an intuitive manner. In particular, equation (1b) confirms the Samuelson [1963] result that the portfolio variance rises with the number of risks M and with the square of each investor's share of the portfolio α.

Now assume that each shareholder of the insurance syndicate has a utility function U defined over his or her expected income E and variance V from their share of the insurance portfolio:[5]

(2) U = U[E, V], with $U_E > 0$, and $U_V < 0$.

The following effects of <u>ceteris paribus</u> parameter changes are easily derived from equations (1) and (2) (U_E and U_V are the partial derivatives of the utility function (2) respect to E and V respectively):

$$(3a) \quad \frac{\partial U}{\partial e} = U_E \boldsymbol{a} M > 0,$$

$$(3b) \quad \frac{\partial U}{\partial r} = U_V \boldsymbol{a}^2 (M^2 - M)(V_i) < 0,$$

$$(3c) \quad \frac{\partial U}{\partial \boldsymbol{a}} = U_E \boldsymbol{e} M + U_V 2\boldsymbol{a}\{(1-\boldsymbol{r})M + \boldsymbol{r}M^2\}V_i > 0, \text{for } \boldsymbol{a} \text{ small (i.e. for N large)},$$

$$(3d) \quad \frac{\partial U}{\partial M} = U_E \boldsymbol{a} + U_V \boldsymbol{a}^2 (1 + \boldsymbol{r}(2M-1))V_i \overset{>}{\underset{<}{}} 0.$$

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[5] In assuming that the portfolio is divided equally among the investors, we are in effect assuming identical preferences. With heterogeneous preferences, the optimal shares would be as in Wilson [1968].

Result (3a) indicates that investors can always be induced to participate in the insurance syndicate by making the premium loading ε sufficiently large. Result (3b) indicates that utility is always decreased when the correlation coefficient ρ increases. Result (3c) indicates that a risk averse investor will always take on an investment with a positive expected return, as long as the investment position can be made sufficiently small; see also Samuelson [1963]. Result (3d) indicates that the change in utility is not signed when the number of risks M is increased, though when the investor's share of the portfolio α is sufficiently small, adding risks does increase utility.

The key implication is that investors would always be willing to participate in such an insurance syndicate portfolio as long as either the portfolio loading ε is sufficiently large and/or the number of investors N is sufficiently large (meaning that each investor takes on only a sufficiently small share α of the portfolio). This conclusion is true, moreover, even when the expected loss E_i or variance V_i of each policy is large and/or when the individual risks are highly (even perfectly) correlated. Of course, when the risks are larger or more highly correlated, then the premium loading ε or the number of investors N will itself have to be larger in order to induce investors to purchase a share of the portfolio.

In interpreting this result, we must be careful to include any costs of running the insurance syndicate within the insurance loading ε. There are two sets of such costs to consider. First, there are the standard operating costs of insurance firms. Second, there are performance guarantee costs, which arise from the need for an insurance firm to provide its policyholders with assurance that the firm will have the resources to satisfy claims. Examples of performance guarantee costs are the costs of capital requirements and of participating in state guarantee plans. Operating expenses and guarantee costs both have the effect of raising the required premium

loading. The almost universal willingness of individuals to purchase policies from insurance firms for standard casualty risks (such as auto insurance) suggests that the risk-sharing benefits of insurance firms are generally sufficiently large to cover the premium loadings required by these additional expenses.[6]

The Special Case of Terrorist Insurance

Terrorist insurance is just a specific type of casualty risk in terms of the above analysis. In particular, the result, that investors can always be induced to hold such an insurance portfolio if the premium loading ε or the number of shareholders N is made sufficiently large, applies to terrorist insurance as much as any other casualty risk. In this context, terrorist insurance, or indeed any type of extreme event insurance, is not of another kind.

On the other hand, terrorist insurance may be of a significantly different degree. The parameter values that reasonably apply to terrorist insurance in equation (3) might be significantly different from those that apply to more standard casualty lines such as auto insurance. In particular, for terrorist risks:

i)   the size of the risks as measured by E_i or S_i may be larger;

ii)   the correlation coefficient ρ might be higher,

iii)   the performance guarantee costs may be higher (as a result of (i) and (ii)).

The implication of these differences in degree is that the premium loading ε and the number of investors N necessary to induce investors to hold a terrorist insurance portfolio is likely to be larger than for more traditional casualty risks. This is a question of degree, not of kind, since in principle there is nothing unique about terrorist insurance in the context of this analysis.

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[6] For a recent set of studies reviewing auto insurance in the United States, see Cummins [forthcoming].

Our conclusion is thus if capital markets are "perfect" and all investors hold highly diversified market portfolios, including equity positions in insurance firms, then these firms would be an efficient structure for holding even large and highly correlated terrorist risks. There are, however, two sources of capital market imperfections that could frustrate this result, namely asymmetric information within the syndicate, and bankruptcy/agency costs. We now consider these in turn.

Asymmetric Information

In forming an insurance syndicate, there is always the possibility that some members will have more information regarding the risks at issue than others. This problem is distinct from the insured/insurer adverse selection problem referred to earlier. But this source of asymmetric information too can lead to market failure. It is unclear, however, why asymmetric information should be a more important problem for an insurance firm selling terrorist risks to capital market investors than for selling, say, auto insurance risks. While terrorist risks may be large and there may be substantial uncertainty concerning even the estimates of these risks, none of this uncertainty should cause substantial asymmetry between the insurance firm and its capital market investors.

Bankruptcy/Agency Costs

If the losses created by a terrorist attack threaten an insurance firm with bankruptcy, then there is a potential for deadweight bankruptcy costs and related agency costs. In particular, it is clear that the probability that an insurance firm would be made bankrupt by a particularly bad terrorist loss during one year is substantially higher than the probability that the same firm would be made be bankrupt by a particularly bad run of, say, auto insurance losses during a year. It

could thus be quite sensible for the insurance firm's management to refuse to take on terrorist risks for fear that a "big one" will cause the loss of their jobs due to the bankruptcy of their firm. These agency costs would be particularly high if terrorist insurance is provided by firms who are also earning significant profits by providing casualty insurance over the full range of normal lines. In this case, the bankruptcy costs that result from a bad terrorist loss might include the loss of the discounted value of the future profits from all the other insurance lines as well.

On the other hand, it would be appear that agency costs created by prospective bankruptcy could be avoided by appropriate security structures for the insurance firm. As one example, specialist insurance firms could be created to hold only terrorist risks, thus avoiding the possibility that a major terrorist loss could disrupt an otherwise profitable insurance firm. As another example, traditional insurance firms could securitize their terrorist risks, selling them directly to capital market investors. In fact, markets for securitizing natural disaster risks, such as earthquakes and hurricanes, have already been developed. Thus, while bankruptcy/agency costs might be a short-run problem for traditional insurance firms in providing terrorist insurance, in principle the problem should be solved by quite straightforward institution or security design. As we discuss later, however, these arrangements face a number of practical difficulties and its remains to be seen whether or not these difficulties can be overcome.

4. <u>Post Event Behavior</u>

In the previous sections we have examined the conditions necessary for the formation of an extreme event insurance syndicate. In fact, we know that following the September 11 event, previously well-functioning markets for terrorist insurance basically ceased to exist. Similar breakdowns in insurance markets occur regularly following similar catastrophic events such as hurricanes and earthquakes. In this section, we now suppose that the extreme event has occurred.

Going forward, we want to consider why the simple occurrence of a low probability, high consequence, event should cause previously well functioning insurance markets to cease to function.

It is true, of course, that the occurrence of an event may contain information requiring the reassessment of the means variance and covariances of the underlying risks. But after an appropriate adjustment in premiums it would appear insurance syndicates should again be viable. Clearly, however, this is not what happens. Typically, following an extreme event, insurance markets are seriously disrupted. This was the case following terrorist attacks in Northern Ireland then again following terrorist attacks on the UK mainland. This was also the pattern following the Northridge earthquake in California, following Hurricane Andrew in Florida and, most recently, following the events of September 11.

We offer two sets of explanations for this type of market failure, one based on issues associated with capital market depletion, the other associated with behavioral responses to bad draws. We begin by examining capital markets.

Explanations for Post Event Behavior: Capital Markets

Extreme event losses tend to be large. Even with the risk spreading associated with reinsurance, any one risk bearing entity can find its capital depleted when the loss exceeds $50 billion.[7] It is worth noting that in this respect extreme event insurance differs sharply from "routine" property casualty underwriting. In "routine" lines such as auto insurance or dental

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[7]Though in the case of Lloyds, for example, risk sharing would appear to have significantly mitigated the September 11 loss to any one syndicate. Of the estimated $8 billion in claims (as of November 4, all but $1.9 billion was laid off to other reinsurers. This $1.9 billion in turn was shared among 75% of the syndicates, suggesting to outside observers that no one syndicate was disproportionately hit, Joseph B Treaster, "Lloyds says It Can Pay, But Officials Seek Proof," New York Times Nov. 4,2001. Still, on September 24, A.M.Best moved Lloyd's from an A to an A-rating. This would be expected to have some impact on their ability to write business, see Epermanis and Harrington [2001].

insurance, one year's premiums will essentially cover one year's losses. The syndicate which provides the insurance places very little of its own capital at risk. In the case of extreme events, however, if the event occurs early in the life of the syndicate, the premiums accumulated so far may fall far short of the loss, leaving the syndicate responsible for the shortfall.[8]

In a previous paper on natural catastrophe insurance (specifically earthquake and hurricane risks), Jaffee and Russell [1997], we have discussed what is essentially the same liquidity problem. That paper points out 3 fundamental problems with the strategy of pre-funding expected losses by accumulating reserves:

i)   U.S. accounting rules preclude "ear-marking" retained profits as "reserves" against future losses, if the actual events have not yet occurred.

ii)   U.S. tax rules require full taxation of profits that are being retained as reserves against future losses.

iii)   A firm that accumulated liquidity against future large losses would find itself at the risk of a takeover, in which the acquirer would plan to allow the insurance liabilities to expire, and then use the cash for some other purpose.

This leaves an after event issue of new capital as the only feasible means of restoring the capital base. Note that the major insurers in the US have all been sufficiently well capitalized to withstand all of the recent catastrophe losses in the US . Nevertheless, when the time has come to replenish their capital, many firms have refused to do so.

This is difficult to understand in that the period following an event is in many ways the perfect time for a syndicate to raise new capital. Rates normally harden following an event (in the case of September 11 rates have hardened significantly), and this will be reflected in stock

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[8] This problem could be avoided by creating decade-long insurance contracts, while still requiring that premiums be paid at the initial date of the contract. However, policy-holders would then face the serious performance risk that the company would be unable to pay its losses because the firm used the acquired premiums for some other purpose. The fact that we do not see such long-term contracts suggests the performance guarantee issue is serious.

prices., lowering the cost of equity. For example, the S&P Insurance Index, (IUX) which stood at 686.85 on Sept. 10 had reached 732.28 by October 3. (Of course as with all stocks, there was a fall at the reopening of the markets, an event which itself may need further explanation.) Even an individual company such as Chubb which was widely reported to have large exposure to the event had a stock price on October 3 of 76.92 as compared to its closing price on September 10 of 66.47.

However, there are difficulties in accessing capital markets <u>ex post</u>, again discussed in Jaffee and Russell [1997]. An insurance firm is unlikely to issue new securities following a high-loss event for 2 reasons:

a. Potential investors in the new securities will be concerned that their new funds will be used just to pay off past losses, not to support new profitable initiatives. This becomes a particularly serious issue when the actual amounts of losses from the current event remain unknown. In this case, claimants play a role similar to bond holders in the classic Myers debt overhang argument; see Myers [1977]. It would not seem impossible, however, to pen these existing losses off, if necessary by starting a new firm, and in this case this problem goes away.

b. The potential for asymmetric information may lead potential investors to evaluate future risks at a higher level than does the issuing firm, causing the new investors to require a lower price for the new securities than the firm is willing to accept.

On the other hand, a number of insurance derivatives have been created in recent years, including option and futures contracts and catastrophe bonds. These securities are motivated by the notion that catastrophe events represent, by and large, zero beta risks, so that capital market

investors should be willing to take on these risks at a premium that reflects only the expected loss, and with little or no risk premium above that amount.

These instruments have also been analyzed in Jaffee and Russell (1997). They point out that these securities have also failed to provide an effective mechanism for transferring catastrophe risks from insurance firms to the capital markets, for two basic reasons:

a.   Just as with new security issues, the potential for asymmetric information may lead potential investors to evaluate future risks at a higher level than does the issuing firm.

b.   With the future and option instruments, the need to provide an adequate performance guarantees has restricted the amount of risk transfer to relatively small amounts.

In California, following the Northridge earthquake, a small quantity of private capital did return to the earthquake line, but earthquake insurance is still primarily offered via the state run CEA. It is possible that the existence of this agency made it unnecessary for insurance companies to consider raising new capital. To date (January, 2002), there have been no new issues of capital to restore the capital lost by the terrorist attacks. This too may be because insurance and reinsurance companies expect eventual federal government assistance. For whatever reason, it is clear that new capital does not immediately flow into catastrophe lines following an event, so that private insurers either limit coverage or withdraw from the line completely. In the next section we offer behavioral explanations for this phenomenon including a new explanation based on a behavioral interpretation of attitudes to risk.

Explanations for Post Event Behavior: Psychology

There are at least two possible behavioral explanations for the observed market disruption. The first is based on notions of fairness as discussed by Kahnemann, Knetsch, and

Thaler [1986]. In this view, when events require a sharp increase in price, markets may fail because the seller is reluctant to incur the bad will caused by an apparently unfair price increase. That fairness may play a significant role in the explanation of the regulation of insurance markets has been developed elsewhere, Jaffee and Russell [1998]. It is less obvious that it plays a significant role here.

In the first place, as Kahneman, Knetsch, and Thaler note, unfairness is generally associated with price increases for which there is no obvious cost justification. In auto insurance in California in the late 1980s, for example, rate increases were viewed as being unfair because the typical driver had accidents infrequently and therefore did not know that repair costs had escalated. Premium increases therefore seemed to be a form of gouging. Events such as earthquakes or hurricanes or terrorist attacks, however, are all vivid and widely reported. The widespread reporting of damage before an increase in rates would blunt the accusations of opportunism.[9]

Indeed, as we saw in the case of Chicago's airports, rates have risen and indeed have risen sharply. The complaint from corporate buyers is only partially that rates rise. (After all in many cases, rate increases can be spread over many final buyers as in the case of all airline travelers through O'Hare). When insurers are prepared to raise rates tenfold for extremely limited coverage, it is hard to see that fairness is the central explanation. The supply failure

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[9] Even so, following the Northridge earthquake of 1994, many insurance firms reported consumer resentment of a doubling of their premiums, even though the companies had just reported losses that offset most of their profits on this line for the previous 10 years. Furthermore, it is reported that at the same time, the state's insurance commission rejected requests for premium increases, even though they were based on the actual payment of substantially higher costs of reinsurance. So, fairness may remain a serious issue, even it if the basis for the issue is an inaccurate understanding of the facts by customers or regulators

seems to lie deeper than this. We now explore another explanation which we may call irrational abhorrence.

Irrational Abhorrence

The models of decision making which underlie the analysis of insurance presented so far have all been relentlessly cognitive. Recently, however, some researchers have recognized that decisions under uncertainty involve additional psychological considerations. In a recent survey on which we draw, Loewenstein et al [forthcoming] have called this new approach "Risk as Feelings." This literature recognizes that decisions under uncertainty produce visceral reactions which can interfere with and indeed supercede rational cognitive processes.

It should be noted that this literature goes beyond the " errors in judgment" literature associated with the names of Tversky and Kahneman [1973]. Certainly "the availability heuristic" of Tversky and Kahneman would suggest that after a particularly vivid event the probability of another similar event is over-estimated, but this simply means that the mean variance covariance data used to price insurance is objectively "wrong". It does not explain why the market suddenly ceases to exist.

Consider, by analogy the market reaction to another extreme event, Following the stock market downturn of Oct. 1987, the valuation of index puts suggested that the market was placing a higher probability weight on another downturn than was warranted by base rate data, see Bates [1991], Rubinstein [1994]. This would be equivalent to using the wrong data to price insurance. Of course, as time passed and another downturn did not occur, market pricing returned to its former structure We discuss this type of market behavior later when we consider public policy.

Our concern here is not with wrong pricing but with the out and out refusal to trade. As we will now show, a withdrawal of supply is predicted in the "risk as feelings" literature, where

non-cognitive factors lead to inaction rather than wrong action in the face of some risks.[10] These non-cognitive factors have been extensively studied by Slovic and his collaborators. Peters and Slovic [1996], for example, reduced the psychological dimensions of risk to two primary factors, dread defined by Loewenstein et al as " the extent of perceived lack of control, feelings of dread, and *perceived catastrophic potential* (italics added) and risk of the unknown defined as the extent to which the hazard is judged to be unobservable, unknown, new, or delayed in producing harmful impacts.

That dread could lead to inaction and, in the context of terrorist insurance, to a withdrawal of supply, is consistent with the findings of Damasio and his colleagues, see Bechara et al [1997]**.** As reported in this study, subjects were told that they could earn hypothetical money by turning over cards from one of 4 decks. Two of the decks contained high payouts ($100) and two contained low payouts ($50). The high paying decks, however, also contained a "catastrophe", a card marked with a very high loss. For our purposes it was an unfortunate part of the experimental design that this cat card had a loss so high that the expected value of the decks containing it was negative. Nevertheless the ensuing behavior is of great interest.

Some subjects in this study were patients with cortical brain damage, while others had no such damage (the controls). Focusing on the controls, on average these subjects sampled from all four decks until they drew the cat card. After that, they ceased to sample from this deck. It must be viewed as an open question at the moment whether or not if the design was changed to make the decks with the cat cards be of higher expected value, subjects would still avoid this deck. Nevertheless, the observation that individuals shun investment opportunities which have just

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[10] Refusal to trade can be motivated by other non-Laplacian models. For example, if the individual exhibits behavior represented by a Choquet integral, then refusal to trade can be a consequence of "model uncertainty". See Routledge and Zin [2001].

experienced a major loss does provide a unifying framework for the analysis of a number of extreme event phenomena. We focus on two issues here

Good and Bad Multiple Equilibria.

Since the essence of insurance is risk sharing, it is essential that anyone contemplating joining an insurance syndicate believes that there are enough other potential members of the syndicate to make his or her share of the risk small. This seems to have been the case pre September 11. However, following the event, even if a non-emotional investor believes that the syndicate could be profitable if sufficiently subdivided, the syndicate will not be viable if

a) the event causes a sufficient number of investors to become unavailable, or

b) it causes sufficient investors to have the belief that a sufficient number of investors will be unavailable.

In the latter case the belief that the syndicate was not viable becomes a self-fulfilling prophecy.

Heterogeneous Response

It seems unlikely that all investors will pass on a positive profit project just because it once generated a bad draw. Because of its neurological basis, the research of Damasio and his associates focuses on extreme heterogeneity, using the fact that some of the subjects had suffered neural damage. It was found that these subjects returned to the "cat decks" more quickly, the assumption being that these subject's visceral response were neurologically attenuated. But heterogeneity across normal subjects has also been noted by Peters and Slovic [forthcoming].

It seems clear that some individuals are less prone to "irrational abhorrence" than others. The basis of this variation across individuals lies outside the scope of economics, but there does seem to be an interesting difference between the response of individuals and the response within corporations. For example, following the cancellation of the 2002 Soccer World

Cup insurance by the large French insurer AXA, Warren Buffett, an executive who exercises strong individual control over his insurance companies, quickly offered to fill the gap. This was not the first time Buffett had intervened to take away a contract from an established player. In 1996, acting through National Indemnity, a division of Berkshire Hathaway, Buffett at the last minute undercut the cat bond arrangements of the California Earthquake Authority . Interestingly, the effect of this was a rise in Berkshire's stock price relative to the market. Buffett is also alleged to have undercut a cat bond issue by XL in 1999, Froot [1999] [11]

It would appear that the tendency to stay away form projects which have suffered a loss is more pronounced in corporations with all their well known agency problems than it is in entities run by single individuals,. This seems somewhat paradoxical because we would expect that cold blooded calculation would be more prevalent in entities run by professional managers.

5. **Public Policy and the Market for Extreme Event Insurance**

How should public policy be conducted when insurance firms and/or capital markets "dread" the prospects of carrying terrorist insurance risks. This is a deep question with implications beyond the question of how to restore the terrorist insurance market.[12] In this section, we discuss a range of alternative policy solutions.

Adequate Premium Levels

An immediate question is whether the primary insurers are able to charge premium levels that make terrorist insurance policies actuarially sound. As discussed above, these insurers may well feel they are unable to charge adequate premiums, either due to regulatory constraints, or because the firms want to avoid the customer ill-will that would arise when customers feel the

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[11] Froot [1999], " The Market for Catastrophe Risk: A Clinical Examination,* July 25 1999.
[12] For example, how should cost/benefit analysis be conducted if citizens evaluate costs and benefits emotionally?

premiums are unfair. Indeed, in the aftermath of hurricane Andrew and the Northridge earthquake, adequate premiums did not seem to be available (see Appendix 2), and the private market for hurricane and earthquake catastrophe insurance was thereby doomed to failure.

As of this writing, regulatory limits on premiums and customer protests of unfair premiums appear to be much less an issue for terrorist insurance following September 11 than they were for natural catastrophe insurance following hurricane Andrew and the Northridge quake. There are two main reasons for this difference. First, of course, all the market participants—customers, regulators, and insurance firms—have the benefit of hindsight with regard to what did happen in the market for natural catastrophe insurance. Second, the issue of terrorist insurance is primarily a question of commercial insurance, whereas the natural catastrophe insurance was primarily an issue of personal homeowners insurance. This matters because regulatory powers are much weaker for commercial lines and because commercial firms appear to be less willing and perhaps less able to marshal public protests against unfair premiums.

Furthermore, as a practical matter, recent discussions of the future structure of the market for terrorist insurance have focused almost exclusively on how to provide an adequate supply. The assumption that actuarially sound premiums are being charged is implicit in these discussions. In this section, we follow this line, and make explicit that we are assuming that the primary policies for terrorist insurance are based on actuarially sound premiums.

The policy problem to be addressed is that private insurance firms appear unwilling to offer terrorist policies, even though these policies can be priced with actuarially sound premiums. As discussed earlier, this failure of the market for terrorist insurance can be understood as a capital market failure, as a psychological reaction, or quite possibly as a

combination of the two. Whatever the detail, the issue before the policy maker is how to revive the market. We now look at a several solutions.

A Limited Liability Pool

One solution, or possibly just one part of a solution, is to form what we will call a limited liability pool, or LLP. The idea is to create a quasi-public entity which would hold all terrorist insurance risks, and be solely responsible for making payments to policyholders. The California Earthquake Authority (CEA) is a good example of a LLP. There are two key features. First, the participating primary insurers must transfer all their terrorist risks to the LLP, thus eliminating any financial connection between their firm and the payment of terrorist losses. Second, the LLP has no claim on government resources. This means that the capital resources available to the LLP for paying claims include only its initial capitalization, its premium income, and its retained profits (see Appendix 2 for details on how the CEA worked in this regard). The result is that in the event of a really "big one", policy holders will not receive full payment for their losses. This possibility was explicitly recognized in the legislation creating the CEA, although there is, of course, the question what a government would actually do in the event.

Limited Liability Pool + Insurer of Last Resort

An obvious failing of the LLP is that policy holders must basically self-insure the top tier of their terrorist risk, exactly what the welfare economics of insurance implies should not happen. This can be solved, however, if the government is willing to step in and reinsure the top tier of losses that are beyond the capacity of the LLP. We refer to this as the insurer of last resort function.

The Pool Re agency for terrorist insurance in Great Britain is a good example of a limited liability pool combined with a insurer of last resort. Pool Re, in fact, is similar to the California Earthquake Authority, in that it is a quasi-public entity in which participating primary insurers place their terrorist risks. Unlike the CEA, however, the British Treasury provides Pool Re a further reinsurance policy to backstop all its losses. The result is that British government guarantees full payment on any terrorist losses. Appendix 1 describes the details of the Pool Re plan, including the mechanisms for allocating premiums and losses between Pool Re itself and the Treasury.

Catastrophe Bonds as Insurer of Last Resort

A major drawback to the limited liability pool, whether or not it is combined with an insurer of last resort, is that the primary decisions of insurance underwriting and pricing are taken out of the hands of the private market.[13] This could lead to a variety of operating inefficiencies, including the possibility of subsidized or cross-subsidized premiums. It is thus useful to consider catastrophe bonds as an instrument which could retain the participation of the private firms in the underwriting process, while addressing their need to avoid bankruptcy if a very high loss event were to occur.

We use the term catastrophe bonds here to refer to a class of securities, issued by insurance or re-insurance firms, with the key feature that if a prescribed catastrophic event occurs, then the insurance firm can use the cash from the bond sale to pay its insured losses, and the insurance firm is then relieved of its obligation to repay the principal on the bonds. A limited number of catastrophe bonds have been issued by insurance firms to hedge their hurricane and

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[13] Otherwise, the private markets would have incentive to cherry-pick, keeping the best terrorist risks in their own portfolio and passing the others to the public pool.

earthquake risks, but the high risk premium required so far by capital market investors has limited their usefulness. Catastrophe bonds could also be used by insurance firms to sell terrorist risks to capital market investors, although the same question of pricing is likely to arise.

To overcome this pricing problem, one solution would be for the US government to purchase specific tiers of terrorist-catastrophe bonds, representing the riskiest layers of terrorist risks. The catastrophe bonds would substitute for the role held by the British Treasury as insurer of last resort under the British Pool Re plan. The advantage of the catastrophe bonds is that the primary insurance firms could then underwrite and hold the policies directly, since the catastrophe bonds will hedge the tiers of terrorist risk that might otherwise threaten their solvency.

Catastrophe bonds sold by insurance firms to the government represent the securitization of insurance risks, and government ownership of the bonds can be seen as parallel to the implicit and explicit guarantees that the U.S. Treasury currently provides to Fannie Mae and Freddie Mac to back their mortgage market securitization.[14] Treasury guarantees of mortgage market securitization are currently under attack because (1) they are provided without charge and (2) they may no longer be needed to support the market for mortgage securitization. Our proposal would avoid these difficulties by requiring the insurance firm to pay an appropriate guarantee fee to the Treasury and by having a sunset provision built into the legislation.

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[14] Of course, our proposal for catastrophe bonds makes the government contractually responsible for the associated losses, whereas the government's guarantees for Fannie and Freddie are mainly implicit. Nevertheless, if the bottom line is that when a major loss occurs, the Treasury bails out the institution, then the two mechanisms are essentially the same.

<u>Lender of Last Resort versus Insurer of Last Resort</u>

Guaranteed catastrophe bonds still imply a potential government presence as the insurer of last resort, so it is worth considering whether even that role can be minimized. One notion would be to transfer the <u>insurer</u> of last resort function to that of <u>lender</u> of last resort. The distinction between these can be seen clearly in the government's role with respect to the U.S. banking industry. The insurer of last resort for bank depositors is the Federal Deposit Insurance Corporation. Commercial banks, however, also use the "discount window" of the Federal Reserve, often referred to as the lender of last resort. Federal Reserve discount loans are available to banks only to meet their needs of liquidity, not to help maintain their solvency. Indeed, the Federal Reserve takes care that discount loans are fully collateralized, so that in effect the Federal Reserve stands even before depositors in the case of bankruptcy,

The concept of the lender of last resort could be applied to terrorist insurance if a government agency, possibly the Federal Reserve itself, stood ready to make loans to insurance firms who were in need of liquidity to pay terrorist insurance losses, or to replace the capital already used to pay such losses.[15] These loans might appear similar to catastrophe bonds, but (a) would be issued only after the losses occurred, and (b) would be fully collateralized by assets of the insurance firm. The idea is for the loans to be repaid from the insurance firms' ongoing profits.

A difficulty, of course, is that casualty insurance firms hold relatively little capital, so that their primary asset available to serve as collateral is their going concern value. In this sense, the loan instrument could be seen as a form of subordinated debt, in which the government's claim would be ahead of shareholders, but behind policy holders. If an insurance firm's profits proved

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[15] The terrorist insurance bill currently in front of the US House of Representatives anticipates a similar mechanism for Treasury loans to insurance firms; see Appendix 3.

inadequate to make the loan payments, then the government would have to take over the firm and sell it at the best possible market price. In this case, the government would suffer a loss, so that it would have some risk as lender of last resort, although distinctly less than as the insurer of last resort. It is also an open question whether access to such a lender of last resort, without an insurer of last resort, would provide sufficient incentive for major insurance firms to continue to commit their capital and other resources to the terrorist line of insurance. To be clear, insurers have frequently stated that they must be assured that their maximum possible loss is manageable a number, and this condition may <u>not</u> be satisfied if the government's only role is to be lender of last resort.

Finally it should be noted that the "risk as feelings" literature does not support the argument that the government should do nothing just because objective analysis shows that the market is profitable. Temporary disruptions caused by "irrational abhorrence" impose severe costs on some industries (for example airline transportation) and anything which overcomes this emotional response will increase welfare.

6. <u>Conclusion</u>

In this paper we have attempted to understand why the occurrence of an extreme event causes supply problems in the market for extreme event insurance. Although more standard explanations such as <u>ex post</u> moral hazard and adverse selection in syndicate formation surely contribute to an explanation of the market failure, the timing of this failure as a response to the occurrence of a loss suggests that the "there is nothing to fear but fear itself" syndrome may play an important role.

In this case, the goal of government policy should be not to replace the market, but rather to calm the market until it restores itself. The alternatives for government policy range from

direct government insurance (such as in Northern Ireland and Israel), to insurer of last resort (such as with the British Policy Re or possibly with guaranteed catastrophe bonds), and finally possibly just to be lender of last resort. Generally speaking, the less government intervention the better, but the key is to make sure that capital continues to flow into these lines.

Memories fade after an extreme event, and with the help of government guarantees, it is to be expected that markets will soon return to normal operation. At that time, government support can be withdrawn. The government however, needs to make a standing offer of support—whatever the specific form--so that the market knows that after any event of sufficient scale, government support will be always be forthcoming.

Appendix 1. <u>Terrorist Insurance Around the World</u> [16]

An examination of the behavior of the market for terrorism insurance in other countries reveals remarkable parallels to the situation in the U.S. So long as terrorism was not an issue, terrorism insurance was readily available, but as soon as terrorist activities occurred, a terrorism exclusion clause was drafted and private insurers withdrew from the market. The resulting crisis then provoked demand for government intervention leading to the government becoming the terrorism insurer of last resort.

<u>Spain</u>. In Spain, terrorism insurance is covered by the "Consorcio" system a mandatory government scheme financed by rates on property values. Private insurance is also available, but if it is used, contributions to the Consorcio are not waived.

<u>France</u>. In France, where terrorism has not been an issue recently, insurers are required to contribute to a pool which provides protection against personal injury. France also has a scheme of catastrophe reinsurance called CAT NAT financed by a tax on all property premiums. It is widely believed that if terrorism became an issue in France, CAT NAT would be extended to include this risk.

<u>South Africa</u>. In South Africa, private insurers withdrew from the market in 1976. This led to the establishment of a government backed pool of 15 of the largest insurance companies known as SASRIA (South Africa Strikes and Riots Insurance Association). The South African government is the Pool's insurer of last resort.

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[16] This section draws on the information available at http://www.drj.com/special/wtc/w3_066.htm. Since September 11, both Germany and France have proposed Government solutions similar to the British system Pool Re discussed below.

Northern Ireland. In Northern Ireland, private insurers withdrew from the terrorism line in 1977. The Irish government then passed the Criminal Damage (Compensation) Northern Ireland Order of 1977. This act provides compensation from the government for terrorism losses, payments being made out of general tax revenue.

Israel. Israel, perhaps because as in Northern Ireland terrorism is such a frequent occurrence, has a similar scheme. Property damage from terrorist acts is compensated from the State Property Tax and Compensation Fund, and personal injury is compensated from a state run scheme administered by the National Insurance Institute. Both schemes require mandatory participation with the Government bearing all the risks, and both schemes are funded by general tax revenues.

Great Britain.[17] Perhaps of greatest interest here (because it has been proposed as a model for Federal insurance in the U. S.) is the system of terrorism insurance in Great Britain. (This system as indicated above, is not in force in Northern Ireland.) Since the IRA terrorist attack in Central London in 1993, terrorism insurance in Great Britain has been provided through a Government organized special agency called Pool Re. This agency is a mutual insurance company with (as of the end of 1999) 213 members. Its only function is to provide reinsurance of losses on commercial property sustained as a result of a terrorist act as defined in the enabling statute.

With respect to these losses, the primary insurer is responsible for the first 100,000 Pounds ($150,000 approx.) of loss, Pool Re being responsible for the excess up to the limits of primary coverage. The standard commercial property insurance contract now excludes terrorism caused losses but restores this risk as an endorsement for which there is a separate premium. This

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[17] See, for example, Tillinghast-Towers Perrin [2001].

premium is rated primarily on the location of the property, and 100% of this premium is ceded to Pool Re. The British Government then acts as a re-insurer to Pool Re.

Payment of claims by Pool Re is in layers as follows.

1) From accumulated underwriting profits until this is exhausted then

2) From an ex post assessment of up to 10% of current year terrorism premiums ceded to the pool and then

3) From investment income on accumulated reserves (if any) and then

4) From the British Government Exchequer. There is no limit to the size of the Government obligation as insurer of last resort, but the Government has already offset its liability with a bank loan of 500 million pounds.

Pool Re pays no premium for this re-insurance, until its accumulated surplus reaches 1 billion pounds. (At the end of 2000 the accumulated surplus was 665 million pounds. When (if) the accumulated surplus reaches 1 billion pounds, Pool Re must reimburse the Government the greater of

a) 10% of the net premium income whish it has received plus compound interest or

b) the sum of losses plus compound interest paid to Pool Re

(both of these over the life of the agency).

Thus so long as the accumulated surplus does not exceed 1b pounds, Pool Re receives limitless reinsurance from the British Government for all losses for a premium consisting of the sum of amounts in paragraphs 1, 2,and 3 above.

Appendix 2. <u>Earthquake and Hurricane Insurance</u>

The US casualty insurance faced two larges recent natural disasters--the Andrew hurricane in 1992 and the Northridge earthquake in 1994. The industry response following each of the two natural disasters was very similar, basically to withdraw from offering hurricane or earthquake coverage. The companies provided three explanations for wanting to depart the particular catastrophe insurance line.

First, and most publicly, they argued that the catastrophe risks now appeared so large and difficult to diversify that the companies faced a "risk of ruin" if they offered such coverage. Furthermore, reinsurance was not an easy solution, since the reinsurers either also withdrew from the market or they greatly raised their premiums. The primary insurers thus argued that it was essential to withdraw from the catastrophe coverage in order to protect the financial integrity of their firm.[18]

Second, the companies pointed to the need to obtain "prior approval" for rate increases from the state insurance commissioner, and their fear that such approval would not be granted. For example, firms pointed out that their requests for higher premiums based on objectively higher costs of reinsurance against hurricane and earthquake risks were denied right from the start.

Third, the companies pointed out that their customers perceived the expected losses from natural catastrophes to be much lower than their own expected losses or the expectations of their reinsurance partners. Thus, the insurance firms feared, were they to go ahead and offer catastrophe insurance at the premiums deemed necessary, they would lose the goodwill of their

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[18] On a related point, the companies pointed to tax and accounting rules which made it difficult and/or costly for them to accumulate reserves to cover future catastrophe claims; accumulating such reserves would also put the firms at risk of an unfriendly takeover.

customers. Since the firms continued to value their relationships with these clients for auto and general homeowner coverage, they decided it was better not to offer natural catastrophe coverage at all, than to offer such coverage at premium levels that the customers considered highly unfair.

Two major strategies were initiated in response to the failure of the primary insurance markets to provide natural catastrophe coverage:

1) The states of Florida and California each created a quasi-public agency that transferred almost all the catastrophe risk from the private industry to the agency.

2) There were a variety of attempts to develop capital market instruments that would allow catastrophe risks to be transferred from the primary insurance firms, or from the reinsurers, to capital market investors. The hope was that the compensation required by capital market investors to take on such risks would not require a significant "risk premium" above the actuarial cost (since catastrophic risks were basically zero beta events)

Appendix 3. <u>Proposed U.S., Legislation</u>

The precise details of the US response to the withdrawal of private insurers is not yet fixed. The current version of this response is contained in House Bill 3210, passed on Nov. 29 2001. This Bill enables the Federal Government to loan the insurance industry 90% of insured losses in excess of $1billion. (The loan is also triggered if losses are in excess of $100m if this loss threatens the solvency of individual insurers.) This loan is to be repaid as follows

a. The first $ 20 billion by an ex post assessment on the industry

b. he remainder by a special assessment on policy holders, though in the case where losses exceed $20 billion, the Secretary of the Treasury has discretion to defer payments and have costs borne by the general taxpayer.

In addition, reserves against terrorist acts could be accumulated free of federal tax. The provisions of the Bill would expire on January 1 2003.

References:

Bates, David S. [1991], "The Crash of 87: Was it Expected? The Evidence from Options Markets" <u>Journal of Finance</u> Vol. 46 pp 1009-44.

Bechara, A. Damasio,H., Tranel, D., and Damasio, A.R. [1997] " Deciding Advantageously before Knowing the Advantageous Strategy" <u>Science</u>, 1293-1295

Cummins, David [forthcoming], <u>Deregulating Property-Liability Insurance: Restoring Competition and Increasing Market Efficiency</u>, American Enterprise Institute-Brookings Institution Joint Center.

Epermanis K and S Harrington, [2001] "Market Discipline in Property-Liability Insurance" NBER Feb. 2001.

Froot, Kenneth [1999], "The Market for Catastrophe Risk: A Clinical Examination", NBER, July.

Froot, Kenneth and Steven Posner [2001], "The Pricing of Event Risks with Parameter Uncertainty," NBER Working Paper No 81906, February, 2001.

Jaffee, Dwight, and Thomas Russell [1997], "Catastrophe Insurance, Capital Markets, and Uninsurable Risks," <u>Journal of Risk and Insurance</u>, Vol 64, No 2, pp 205-230.

Jaffee, Dwight, and Thomas Russell [1998], "The Causes And Consequences of Rate Regulation in the Auto Insurance Industry," (with Thomas Russell), in David Bradford editor, <u>The Economics of Property-Casualty Insurance</u>, National Bureau of Economic Research; (also NBER Working paper No. 5245).

Government Accounting Office [2001], "Terrorism Insurance: Alternative Programs for Protecting Insurance Consumers." US Govt. General Accounting Office

Kahneman, D., Knetsch, J.L., and Thaler, R. [1986] "Fairness as a Constraint on Profit Seeking: Entitlements in the Market" <u>American Economic Review</u> Vol. 76 pp 894-920.

Lowenstein, G.F, Weber, E.U., Hsee, C.K., and Welch, N. [forthcoming] "Risk as Feelings" <u>Psychological Bulletin</u>.

Myers, S.C.[1977], "Determinants of Corporate Borrowing." <u>Journal of Financial Economics</u>, 5:147-176.

Moss David A, [forthcoming], <u>When All Else Fails: Government as the Ultimate Risk Manager</u>, Cambridge Harvard University Press

Moss, David A [1998], "Limited Liability and the Birth of American Industry: Theory Meets History." Harvard Business School Working Paper 98-079.

Ross, Stephen [1999], "Adding Risks: Samuelson's Fallacy of Large Numbers Revisited," Journal of Financial and Quantitative Analysis, Vol 34, No3 September.

Peters, E., and Slovic, P. [1996] "The Role of Affect and Worldviews as Orienting Dispositions in the Perception and acceptance of Nuclear Power" Journal of Applied Social Psychology, Vol 26 pp. 1427-1453.

Peters, E., and Slovic, P. [forthcoming] "The Springs of Action: Affective and Analytical Information Processing in Choice." Personality and Applied Social Psychology Bulletin.

Routledge, Bryan and Stanley Zin [2001], "Model Uncertainty and Liquidity", NBER Working Paper, November.

Rubinstein, Mark [1994], " Implied Binomial Trees" Journal of Finance Vol 49 pp 771-818.

Samuelson, Paul [1963], "Risk and Uncertainty: A Fallacy of Large Numbers," Scientia, 98.

Samuelson, Paul [1971], "The Fallacy of Maximizing the Geometric Mean in Long Sequences of Investing or Gambling," Proceedings of the National Academy of Sciences, 68.

Tillinghast-Towers Perrin [2001], "Update" available at
http://www.towers.com/towers/services_products/Tillinghast/update_pool_re.pdf

Tversky, A. and D. Kahneman [1973], " Availability: A heuristic for judging frequency and probability" Cognitive Psychology 5 pp 207 232.

Wilson, R. [1968] " The Theory of Syndicates" Econometrica, Vol. 36 119-132.