FINANCIAL INNOVATION IN THE MANAGEMENT OF CATASTROPHE RISK

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I. INTRODUCTION

Recent financial innovation in managing catastrophe risk, such as catastrophe bonds and catastrophe options, may be seen as a specific response to the problem of insurance and reinsurance capacity. This view is bolstered by a clear upward revision of estimates of loss potential. Recent earthquakes in Kobe and Northridge, as well as events such as hurricane Andrew, have shifted estimates of maximum potential loss by an order of magnitude. Furthermore, the emergence of modeling firms using large technical and financial data bases, has provided the insurance marketplace with credible estimates of single events that could overwhelm the insurance industry. For example, the U.S. industry faces the real possibility of a $50 to $100 billion loss through a major Midwest or Western earthquake or from a hurricane such as Andrew hitting Miami. Comparing this loss potential with an aggregate industry surplus of a little over $2 billion, illustrates the precarious financial position of the industry. In this view of the world, financial innovation may be seen as an attempt to diversify such potential catastrophe losses over the much larger (approximately $13 trillion) capital markets.

An equally compelling case can be made that such innovation is a natural expression of a conceptual revolution, in which the nature of risk and its impact on firms, has been reworked. This so called revolution is known in financial circles simply as "risk management" and its application spreads across all firms (insurance and non insurance firms) and all manner of risk (insurable and non insurable risk). The timing of this conceptual revolution is not accidental. The potential for managing risk requires the availability of suitable hedging instruments and the blossoming derivative markets have provided the supply. While the term "risk management" has been borrowed from insurance usage, the new risk management is a separate beast. The two defining characteristics of risk management (at least as applied to firms) are a very precise consideration of why risk is costly to firms and an embracing of all types of risk in a co-coordinated strategy.

The first prong of new risk management, why risk is costly to firms, arose from an apparent contradiction between the theory and practice of financial management. The intellectual climate of the 1970's and 1980's was dominated by the capital asset pricing model and its derivatives. Under this view of the world, risk to a corporation passes to its stakeholders, notable its shareholders. But since shareholders can, and do diversify their portfolio holdings, there should be no gain in value to the firm that hedges risk. Why would investors reward hedging firms when investors could replicate any gain on their own account and at low cost? Despite the compelling logic, firms and investors did indeed seem to place value on corporate hedging. The contradiction is resolved in a more convincing explanation of why risk is costly to firms. The explanation has to do with transaction costs. Risk evokes a number of transaction costs for firms and these costs are borne by the firms owners. By lowering risk, one can lower the transaction costs and increase the expected value of gains to investors.

Merely to point out that there was a misunderstanding about why risk created costs to firms, seems a little pedantic. Why does it matter as long as we reduce risk and thereby enhance corporate value? It turns out that there are important practical reasons for wishing to know why risk was causing a problem. If we know the nature of the transaction cost, we can derive a whole new set of risk management strategies. The cost of risk can be addressed not only by reducing the risk, but also by reducing the transaction cost. This pairing of strategies will be called "duality". For example, one reason risk destroys value arises from non-linear tax schedules. One can create after tax value either by reducing risk or by engaging in transactions that effectively linearize taxes. Similarly, risk is costly to a firm with significant financial leverage since risk creates incentive conflicts between fixed income and residual stakeholders. The dual risk management strategies are to hedge the risk or change the leverage. These complimentary risk management strategies can be identified only if we know precisely why risk was a problem.

The second prong of risk management is that it is inclusive in nature. This is sometimes referred to as "global" risk management. The idea is simple. Risk to a firm can come from a number of sources. For example, a manufacturing firm may be exposed to risk from changes in demand, interest rates, commodity prices and insurable exposures. What ultimately matters is the combined impact of all risk exposures and risk management strategy is most effective if it addresses combined risk. This point should be obvious to insurance folk. Just as an insurer can combine insurable exposures and control relative portfolio risk, so a non insurable firm can diversify across its many types of risk (financial, economic, insurable etc). Thus, it would be strange if a firm that accepted enormous fluctuations in value from daily commodity price changes should decide that a $10 million deductible on a liability policy exposed the firm to too much risk.

To bring this discussion back towards the subject of catastrophe risk, first note a corollary of the two features of risk management. Given it is the transaction costs that arise from corporate structure that create risk costs for firms, and that the ownership shares of both insurance and non insurance firms are traded in the same market, the same general principles of risk management should apply to insurance and non insurance firms. I will start with a summary of the results of recent literature on why risk is costly to firms and I will identify the generic pairs of strategies that are available to manage risk costs. This approach can then be applied to the risk management choices for an insurance firm. The structure provides a much richer set of strategies than is usually identified (insurers typically contemplate only reinsurance and leverage management) and shows how the new financial instruments for hedging catastrophe risk have the potential to provide value to the insurance firm. The structure reveals how reinsurance, financial instruments, insurance policy design, leverage management and organizational form can be used jointly or selectively to manage insurer risk. Moreover, these various approaches vary in their ability to relieve the firm of the various transaction costs that seeded the interest in risk management in the first place.

II. WHY IS RISK COSTLY TO FIRMS?

(i) Tax Non-Linearities

Risk is costly to firms because it aggravates a set of transaction costs and thereby decreases corporate value.[1] One simple cost of risk arises from non-linearities in tax schedules. The tax functions facing firms typically are convex i.e., higher levels of corporate earnings usually encounter higher rates of marginal taxation. To some degree, this convexity is built into the tax schedule; initial corporate earnings, like the first dollars of individual earnings, are untaxed at the Federal level. Above this threshold, earnings pass through several marginal rates, settling on a constant rate which currently is 34% in the U.S. But convexity also arises from other features of the tax code. Firms are allowed deductions for certain expenditures such as depreciation and loss carry backs. The effects of such deductions is to increase the range of income which attracts a zero marginal rate. When deductions are exhausted, the tax rate restores to the normal rate thus giving rise to convexity

Given tax convexity, Jensen's inequality implies that expected taxes will be reduced if the riskiness of earnings is reduced. It follows that the after tax value of the firm will rise if the firm hedges earnings risk. If earnings are risky, upside variation causes a large increase in taxes but downside variation causes little reduction of taxes. Thus, earnings stabilization will avoid the large potential upside increase in taxes without sacrificing much of a tax decrease on the downside. In this manner, hedging can create value by reducing expected taxes.

(ii) Managerial Compensation

A second cost of risk to firms arises from its effect on optimal contract design. The efficient management compensation contract involves a trade off between risk sharing and efficiency. Risk sharing considerations favor payment of flat salary to managers since shareholders have a comparative advantage in diversifying. The flat salary avoids payment of a risk premium to risk averse and undiversified managers. But efficiency favors compensation that aligns the interests of shareholders and managers, i.e., performance related compensation such as bonuses, options, etc, that are related to earnings or share value. The problem is that performance related compensation exposes managers to risk and requires the inclusion of a risk premium. In practice, the optimal compensation package usually is one that compromises between efficient incentives and risk sharing, e.g., a base salary plus some performance compensation.

Now, if earnings and share price are purged of risk by appropriate hedging, the trade off between risk sharing and efficiency is avoided. This means that the compensation packet can focus only on the efficiency goal and thus be loaded with incentive compensation, without the need to pay the manager a risk premium.

A variation on this idea is that firms often deal with creditors who are risk averse and hold an undiversified position in the firm. A specific example is the case of insurance firms. Insurance exists because policyholders are risk averse and relatively undiversified. The quality of the insurance product is degraded by the prospect of insurer default. Being risk averse, policyholders will be reluctant to bear this risk, even if it is priced into the insurance contract. The insurer that is able to reduce default risk by hedging, will be at a competitive

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[1]For explanations of the cost of risk see Mayers and Smith 1983, Shapiro and Titman 1985, Froot, Scharfstein and Stein, 1993

advantage. Ceteris paribus, policyholders will be more likely to purchase its policies and/or pay a higher premium than for the policies of a more risky insurer. Thus, a demand for reinsurance, is induced from direct insurance demand (Doherty and Tinic, 1982)

(iii). Direct Costs of Financial Distress

If a firm becomes bankrupt then, according to the absolute priority rule, shares expire worthless and the firm resorts to the creditors. Any transaction costs, such as legal fees, court fees, accounting costs, will be borne *ex post*, by the creditors. In addition to direct costs of bankruptcy, there may be indirect costs, or opportunity costs, which also will fall on creditors. When a firm is administered by the court, the normal incentive structure which leads agents to perform efficiently may be disturbed. Contracts written with managers, agents, employees and others often have rewards and penalties associated with performance. During a bankruptcy, these contracts are sometimes challenged especially if they seem retroactively generous given the firm's current plight. Moreover, new contracts written during such a period are overseen by the court. Will these contracts written under court supervision, carry the same incentive provisions as contracts written during a normal period under which the firm is monitored continuously by the capital market? To the extent that incentive compatibility is sacrificed during bankruptcy, the performance of the firm will suffer. The foregone value will be lost to the creditors who now "own" the firm. Similarly, value may be lost if the selection of investment projects is affected by court supervision. For example, during solvent operations, and capital market accountability, the firm may be aggressive in its project selection and earn the appropriate premium associated with such entrepreneurial activity. If the bankrupt firm is less entrepreneurial in its project selection, any loss of value will fall on the creditors.

The various transaction costs of bankruptcy theoretically fall *ex post* upon the creditors since equity claims have expired worthless.[2] *Ex ante*, these costs will be anticipated in the value of the bonds. Absent any risk premia, the bonds will be reduced by the expected value of the bankruptcy costs. The discount in bond values will reflect investor expectations as to the prospective size of the bankruptcy costs, together with investor expectations about the probability of bankruptcy. Accordingly, any strategy which reduces the probability of bankruptcy (such as hedging) will enhance the value of the firm's bonds and thus reduce the cost of capital.

(iv). Agency Costs and the Under-Investment Problem

Apart from the transaction costs associated with actual financial distress, the prospect of future financial distress causes a number of other problems. The most documented of these is a form of agency which arises between shareholders and creditors, that is often called the "under investment problem". Shareholders have some control over the decision making processes within the firm through their ability to appoint and compensate the management

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[2] In practice, distressed firms are not always re-organized according to the absolute priority rule. Many distressed firms are re-organized in out-of-court settlements or "workouts". These settlements usually, leave the shareholders with some value and the (usually lower) transaction costs associated with workouts will fall jointly (according to negotiation) on both classes of stakeholder.

team (and less directly through their ability to buy and sell shares). Creditors lend their money to the firm without such control over its decision making. Thus, the shareholders are in an agency relationship with respect to the bondholders. This relationship generates opportunities for shareholders to transfer wealth from bondholders by selecting projects with asymmetric payoffs to different classes of investors.

The agency conflict between shareholders and creditors arises from the non-linear nature of claims. Given limited liability, and the residual nature of the equity claim, shareholders will tend to over-value high risk investment projects since part of the downside risk is "put" to the bondholders. This implies that, either the firm will loose value as it fails to select value maximizing investment projects, or that resolution of the agency conflict requires costly controls that limit the discretionary power of managers.[3] Either way, the value of the firm will be reduced. Moreover, if bondholders anticipate such expropriation by high risk project choice, then the cost of debt financing will increase. In this way, the costs of inefficient project selection will fall *ex ante* on the shareholders. This loss of value can be avoided if the shareholders can credibly commit to hedge any high risk associated with new and existing projects. As risk is hedged, the value of the default put falls, and the incentive to select low NPV-high risk projects is removed.

(v). Costly Access to Capital and the "Crowding Out" of Investment Projects

After a firm suffers a loss of assets, such as fire damage to a plant, it is presented with an investment opportunity, i.e., to re-invest in the construction of a replacement plant. Reinvestment only will add value if the net present value is positive. Reinvestment can be financed in two ways. Under *post loss* financing, the funds are secured (from internal or external sources) after the loss has occurred. *Pre-loss* financing occurs if the funds to reinvest in future prospective losses, are secured and paid for before the loss occurs. Insurance is such a source. Premiums are paid in anticipation of possible losses, and the insurance proceeds can be used to finance re-investment without any future interest or dividend obligation. Thus, insurance may be seen as a source of financing for losses, in much the same way as debt and equity are sources of financing. Some financing source is necessary for the firm to capture the net present value of reinvestment. The decision to purchase insurance involves a comparison between the transaction costs associated with insurance (such as commissions, overheads, and moral hazard frictions) with the transaction costs of more conventional capital sources such as debt and equity. It can be seen that one of the benefits of hedging or insurance, is that it permits the firm to undertake value adding re-investment opportunities, which might be lost if post-loss financing is not forthcoming or is too costly.

The analysis of the previous paragraph was developed by Doherty (1985) to analyze insurance and reinvestment decisions. A more general rational for hedging has been developed by Froot, Scharfstein and Stein (FSS) which I will call the "crowding out" hypothesis. The first element is that capital sources have different costs. FSS evoke the work of Myers and Majluff to argue that external capital is more costly than internal capital. The costs associated with capital are then used by FSS to develop their rationale for hedging. First, firms derive their value from identifying and undertaking new investment projects. A

[3]See Jensen and Meckling, 1976 and Myers, 1977.

healthy and growing firm may be investing in research and development, developing new products and rationalizing existing operations. Such firms face a continuing need for capital to fund their investment opportunities. Given the pecking order of the costs of financing, one would expect such firms to adopt a financial strategy (e.g. a dividend policy) to fund as much as feasible of the project budget from internal sources. Now suppose that such a firm takes a sudden loss in liquidity from an uninsured fire or liability suit, a sharp deterioration in exchange rates or an unanticipated rise in the price of a commodity that is used intensively in production. The loss in liquidity compromises the firm's ability to undertake its desired investment projects. Empirical evidence cited by FSS suggests that for each dollar of unhedged loss, project budgets will be cut by about 30 cents. Hedging avoids this loss and protects the ability of the firm to fund its investment program.

III. GLOBALITY, DUALITY AND THREE PRINCIPLE STRATEGIES

The title of this section seems to suggest a conundrum; is it two, three or many? Actually I am addressing three separate issues all of which have an important bearing on the emergence of new risk management instruments and strategies. The issue of globality refers to the idea of assessing the joint impact of all risk from all sources on the value of the firm and forming a co-coordinate risk management strategy. Duality refers to the result that strategies for dealing with the effects of risk on corporate value, come in pairs. Whatever the reason that risk is costly, value can be created either by hedging the risk or by adapting the structure of the firm or its operations such that risk can be borne with lower cost. I will call the second type of strategy "risk accommodation". From these paired strategies, we will isolate three principle generic strategies that lie at the heart of recent financial innovation.

(i) Globality

The various rationales of the cost of risk to a firm suggest that the point of impact is at a highly aggregate level. For example, the tax non-linearity explanation implies that it is the risk of the earnings of the taxable entity in a given jurisdiction, that bestows costs on the firm (i.e., for Federal U.S. taxes, the relevant financial number is the U.S. taxable income). It does not matter whether the income comes from the Idaho plant or the Illinois distribution operation, these values are aggregated for tax purposes. Nor does it matter whether the source of the risk is an insurance exposure or an interest rate fluctuation which impacts earnings. All that matters is the joint impact of all sources of risk on taxable income. When considering financial distress rationales, or the crowding out hypothesis, the level of aggregation is higher. What matters is the joint impact of all sources of risk to the firm on its probability of insolvency, on its leverage and cost of capital, on its share price, etc.. Again the riskiness of an insurance exposure (or an interest exposure, a foreign exchange exposure, etc) does not matter in isolation. What matters is the joint effect of all risk from all sources on the firm's "bottom line". And just as the pooling of many insurance policies will result in a low level of relative risk (assuming low correlation) so too will the combination of various types of risk to the firms (insurable, financial, interest rate, marketing, etc) lead to similar benefits of diversification. This is no more than the law of large numbers (the very basis of insurance). The agency costs between fixed income stakeholders and residual claimants of the firm arise without reference to the source of risk. Moreover, the crowding out of new investments is likely to be equally severe if the depletion of internal funds was the result of an uninsured liability loss or a sudden shift in the price of the firm's major raw materials.

(ii) Duality

In Section II, I outlined five mechanisms by which risk can reduce corporate value. The idea of duality is simple. If risk destroys value, then value potentially can be restored either by reducing risk or by organizing the firm and its operations so that the risk is less costly. In Table 1, I lay out all five forms of risk cost and against each describe two strategies; hedging or accommodation. Consider each of the mechanisms starting with tax convexity. If taxes are convex, then expected taxes will fall as risk falls. Firms have a second option in tackling this problem; they can leave the risk alone but effectively "linearize" their tax obligations. There is a quasi market for firms to "trade" tax shields. The most well known aspect of this market is that for leasing which is driven largely by the lessor retaining ownership of an asset and exploiting its comparative tax advantage over the lessee in depreciating the asset. Similarly, there is some evidence to suggest that reinsurance trade is partly explained as an arbitrage between insurers with different marginal tax rates. (Keun ock Lew 1991, Garven and Louberge 1996).

TABLE 1

TYPE OF RISK COST	HEDG E	RISK ACCOMMODATION
Tax non-linearities	Hedge	Tax Arbitrage-Reinsurance
Financial Distress - agency conflict	Hedge	Reduce Leverage
Financial Distress - ex post transaction costs	Hedge	Reduce Leverage
Cost of Capital - Crowding Out	Hedge	Alternative Financing
Incentive Compatible Compensation	Hedge	Re-write compensation contract

The second mechanism by which risk reduces value was that it compromises the ability of firms to write managerial compensation schemes with efficient incentives. One risk management strategy is simply to hedge the risk so that directors can write incentive compatible compensation schemes (i.e. link compensation to stock price or earnings) without having to pay managers a risk premium. The second strategy is to link managerial compensation to alternative (accounting) performance measures that are purged of risk. This is known as a "phantom hedge" since the risk in earnings (etc) need not be actually hedged. Instead an accounting measure is derived as though there were a hedge in place, and then compensation is based on the accounting measure. Ideally such measures should carry a strong signal of management performance, but should have little extraneous noise; i.e., they should have a low noise to signal ratio.

A similar dual strategy set is available to address the remaining risk mechanisms. The expected value of bankruptcy costs and the agency costs between creditors and equityholders arise jointly from the effects of risk and leverage. Two risk management strategies immediately suggest themselves; reduce risk or reduce leverage. Similarly, with the crowding out hypothesis, reducing risk by hedging will mitigate the problem. But here too leverage management can be used as a complementary or competing strategy. For example, the problem of crowding out can be reduced by maintaining a lower leverage and by reducing dividends. In this way, the firm will be in a stronger position to finance new investment projects from preferred sources of capital even after an unhedged loss.

(iii) Three principle strategies

Of the various strategies identified in Table 1 I will isolate three generic types that are central to the discussion.

Asset Hedge

An "asset hedge" can be defined as an asset which provides a hedge against the risk in some other asset. A portfolio comprising the basic asset and the hedging asset has little or no risk. The asset hedge can be represented in a portfolio F in which an amount \$ is invested in two assets. The first basic asset has a payoff of A_B for each dollar invested. The second asset, the hedging asset, has a per dollar payoff of A_H. The capital \$ is allocated over the two assets in the ratio {1:h} and the correlation coefficient ρ_{BH} is negative (in the limit approaching negative unity).

(1) ASSET HEDGE $F = \$(A_B + hA_H)$ where $0 > \rho_{BH} \geq -1$

If $\rho_{BH} = -1$, then some hedge ratio h* can be chosen such that the portfolio is riskless; i.e. $COV\{\$(A_B + h^*A_H)\} = 0$. A reinsurance policy is a traditional form of asset hedge for the insurer. A newer instrument is the catastrophe option which is an option written on the value of an index of insurance company claims and yields a payoff when the index triggers a pre-set value (the striking price).

Liability Hedge

A hedge can be achieved on the opposite side of the balance sheet. Instead of the hedging asset, the portfolio includes a liability L_H as follows.

(2) LIABILITY HEDGE $F = \$(A_B - hL_H)$ where $0 < \rho_{BH} \leq 1$

If $\rho_{BH} = 1$, then some hedge ratio h* can be chosen such that the portfolio is riskless; i.e. $COV\{\$(A_B - h^*L_H)\} = 0$. Many of the newer risk management strategies are indeed liability hedges.

Leverage Management

Risk accommodation strategies are several, depending on the particular type of risk cost. Tax arbitrage can be appropriate to mitigate the effects of tax non-linearities, and re-writing of managerial compensation contracts can mitigate the adverse effects of risk on managerial decision-making. But I will venture that the most important risk accommodation strategy involves the control of leverage. This strategy can be used to address *ex post* costs of financial distress, the agency costs that arise from leverage and prospective insolvency and the crowding out of new investments. Leverage management may simply involve reduction of the level of leverage. This reduces the agency cost between creditors and residual claimants and reduces the expected value of bankruptcy costs. Moreover, if a sudden loss arises, the firm will find itself in a stronger position to approach capital markets for new funding (either to reconstruct destroyed assets or to fund new investment projects). Alternatively, dividend policy may be used to address directly the crowding out problem. Lower dividend payouts will enhance the ability of the firm to fund future projects from internal funds and reduce the probability that projects will be lost for lack of access to low cost capital.

In applying the above structure to the management of catastrophe loss, I will not discuss leverage management for insurers in any detail. This lack of attention does not reflect its lack of importance as a risk management strategy. Quite the reverse. The use of surplus management and reinsurance to reduce leverage and thereby reduce the probability of ruin, is the subject of an extensive actuarial literature. The newer innovations in insurer risk management have concentrated on new types of hedges, such as cat bonds and futures and this is where I will focus. Indeed it is these new types of financial instruments that are providing competition for traditional reinsurance policies.

IV. CATASTROPHE RISK: INSURANCE, REINSURANCE & FINANCIAL INNOVATION

1. Reinsurance: Credit Risk, Basis Risk and Moral Hazard

Simple diversification will not always remove risk from a primary insurer's liability portfolio. For example, liability insurance is subject to significant correlation, since changes in liability rules can simultaneously affect all policies in an insurer's portfolio. Catastrophe insurance is subject to even more apparent correlation. Thus, the law of large numbers cannot be relied upon to remove relative risk. Reinsurance is the traditional hedging instrument available to primary insurers. However, its use does involve significant transaction cost which are now discussed.

Credit Risk[4]

Catastrophe hedging instruments face design choices that trade off various inefficiencies against each other. Reinsurance can be used to illustrate these trade offs. First, there is credit risk; the risk that the reinsurer will be unable to pay its obligation to the ceding

[4]An aspect of credit risk that is not developed in this paper is liability risk. Litigation does arise between primary insurers and reinsurers over contract wording or over the conduct of the parties. The prospect of non delivery on a reinsurance contract, and the costs of enforcing legal claims against reinsurers are significant costs. The new instruments that are discussed later can be expected to face similar liability risk. For example, one can expect cases in which investors maintain that the dimensions of risk were not properly represented or that the issuer did not act appropriately to control the level of risk.

firm. The recent $17 billion Andrew losses and the $12 billion Northridge losses revealed some chinks in the insurance industry's armor and estimates of a repeat of the 1906 San Francisco earthquake have forecast widespread insolvencies amongst primary firms (Doherty, Kleffner and Kunreuther 1991). Such insolvencies would be transmitted to reinsurers. Indeed, the defaults could be disproportionately large in the reinsurance industry. Many catastrophe reinsurance plans are stop loss A common way in which a ceding firm can off-load risk to a reinsurer is with a "stop loss" (i.e., the contract contains a deductible with the reinsurer paying only the excess above the deductible). Payoffs from such plans only occur when losses penetrate the right tail of the loss distribution. For such payoffs, the coefficient of variation is very high and consequently large catastrophes would probably cause widespread insolvencies. Initial estimations of potential industry payouts for large catastrophes (Cummins and Doherty 1996) support this conclusion with the number of insolvencies rising disproportionately with the size of the catastrophic loss.

Basis Risk

While credit risk is present with reinsurance, basis risk is resolved. Reinsurance payoffs are geared to losses sustained by the primary insurer. Contracts usually cover the primary firm's portfolio losses on designated lines of business (treaty reinsurance), or specific primary policies (facultative reinsurance). Moreover, policies share risk between primary insurer and reinsurer according to linear or non-linear formulae. Thus, while the primary firm will retain some risk, there is no mismatch between the asset on which the reinsurance payoff is defined and the asset to be hedged. In other words, there is no basis risk. It is possible to imagine a "reinsurance" contract with basis risk. If an insurer purchased a reinsurance contract with a payoff structured on the industry losses, rather than on the primary firm's own losses, there would be basis risk. The extent of basis risk would depend on the correlation between industry and firm losses; the lower the correlation, the higher the basis risk. The discussion of basis risk is important since it forms an important design element in structuring new hedges and it can be used to mitigate another inefficiency, moral hazard.

Moral Hazard

Moral hazard is the flip side of basis risk. Moral hazard arises with all insurance policies. With reinsurance contracts, moral hazard can take two generic forms; *ex ante* or *ex post* moral hazard. *Ex ante* moral hazard arises when, due to reinsurance protection, the primary insurer fails to take actions to reduce future losses or takes actions that increase losses. This occurs because the reinsurer cannot monitor the primary continuously and condition the reinsurance contract on the primary's behavior. Thus, the primary firm may be lax in its underwriting procedures, pay inadequate attention to spread of risk and fail to provide adequate risk audits for potential new policies. Naturally, the reinsurer will anticipate this behavior and some level of monitoring will take place. But monitoring is costly and the combination of the costs of monitoring and the excess losses suffered due to inadequate underwriting provides a measure of the costs of moral hazard. These costs are substantial. Industry sources frequently put the transaction cost of reinsurance at 20% of premiums or higher. These direct costs take the form of commissions and premium loading. In addition, many reinsurance relationships are implicitly long term and implicitly experience rated, to compensate for costly monitoring. These temporal relationships constrain the parties and contribute to the costs of moral hazard. It may be noticed that moral hazard arises from the quality of the hedge; i.e., from the absence of basis risk. Consequently, the structuring of a catastrophe hedge, provides the opportunity for trading off these two features.

Ex post moral hazard arises when the loss settlement practices of the insurer are relaxed due to the presence of reinsurance. This is a particular problem for catastrophic losses. The loss settlement capacity of any insurer (and of the industry) is reasonably geared to the normal levels of loss frequency. When an event such as hurricane Andrew arises, primary firms simply do not have the capacity to inspect and negotiate claims settlements thoroughly. Thus, it becomes more difficult to prevent the "build up" of claims (policyholders including uninsured damage in the claim or exaggerating the size of the loss) or outright fraud on the part of policyholders. However, the incentive for the primary insurer to control its claims will be relaxed if it has reinsurance protection. The primary may be able to avoid the abnormal transaction costs of settling claims, and even buy some goodwill with its policyholders by making generous settlements with policyholders and passing the costs of excess settlements to its reinsurer. Also, insurers are often pressured by regulators to be prompt and generous in settling losses in a highly publicized catastrophe. When protected by reinsurance, the primary insurer can achieve regulatory goodwill and pass the cost to the reinsurers.

Of course, there are constraints on this type of behavior. For moderate losses, the primary firm may well consider its reputation in the reinsurance market before engaging in such opportunistic behavior. Primary insurers will seek future reinsurance protection and a history of moral hazard will hardly stand them in good stead. In the event of severe catastrophes, the normal constraints on such insurer moral hazard will be especially dulled. When insurers are facing financial stress, their reputation in returning to reinsurance markets in the future, is unlikely to be so constraining.

A More Formal Look at Moral Hazard and Reinsurance

Let us look at moral hazard a little more formally. The object is to see how moral hazard affects the design of reinsurance contracts and the structure of reinsurance markets. In particular, I wish to be able to show why reinsurance locks the parties together into long term relationships and why these relationships appear so costly relative to hedging instruments traded on financial exchanges. To start, consider a very simple single period valuation model of an insurer. At the beginning of the year the insurer contributes equity capital of E and receives premiums P (net of expenses). The initial funds E + P are invested at a random rate of return r_i for one year and then losses L (also random) are paid. Thus, the terminal value of the insurer's equity is:

$$(3) \quad T = (E+P)(1+r_i) - L$$

Now add in reinsurance. At the beginning of the year, the insurer pays an amount R as a reinsurance premium. The policy assumed is a treaty stop loss policy which pays the insurer when losses on an underlying insurance portfolio I, exceed a deductible (striking price) S. The payoff to the reinsurance can be represented as a call option and we use the notation C(I; S). The term "h" is the hedge ratio, which may be interpreted here as the proportion of the primary's losses above S that is reinsured. Naturally, the premium also depends on I and S (i.e., R = R(I; S)). In normal arrangements, the reinsurance coverage is based on the ceding insurer's portfolio, or some particular lines. There is no inherent basis risk other than that assumed by the ceding company by accepting a deductible. Thus, for reinsurance, we can consider I and L as identical. With other hedging instruments, basis risk can be present and we will keep the distinct notation. The final element is mitigation. The insurer is able to reduce the level of expected loss, by spending an amount "a" on mitigation (better underwriting, loss control, loss adjustment, etc). While mitigation is a direct cost to the insurer, losses will decline as more is spent on mitigation. The terminal value of equity can be shown as:

$$(4) \quad E(T) = \{E-P-R(I; S)\}(1+E(r_i)) - E(L(a)) + h\, C(I; S) - a$$

Now consider that optimal choice of mitigation for the primary insurer.[5] Using normal

$$(5) \quad \frac{\partial E(T)}{\partial a} = -\frac{\partial E(L(a))}{\partial a} - 1 + h\frac{\partial C}{\partial I}\frac{\partial I}{\partial L}\frac{\partial L}{\partial a} = 0$$

optimization techniques, this can be represented by the first order condition:

The first term $(-\partial E(L(a))/\partial a)$ shows the effects of increasing mitigation spending by \$1 on the primary's expected losses; the second term (-1) shows the direct cost of increasing mitigation expense by \$1; and the third term $\{h(\partial C/\partial I)(\partial I/\partial L)(\partial L/\partial a)\}$ shows the effect of the additional mitigation (and therefore reduced expected claims for the primary) on the expected recovery under the reinsurance policy. If there were no reinsurance, the primary insurer would fully internalize the benefits of spending on safety and the third term would drop out leaving (6) in the form $-\partial E(L(a))/\partial a = 1$. This can be interpreted as follows. The primary will spend an amount on mitigation until the additional dollar of expenditure on mitigation brings a reduction of one dollar in expected losses. However, reinsurance disturbs this balance. With reinsurance, the third term becomes important and this will serve to reduce the primary's choice of mitigation. Any benefit to the primary in terms of reduced policyholder claims, simply reduces the reinsurance recovery. The higher the deductible the lower the choice of mitigation. Since reinsurers will rationally anticipate this reduction in mitigation in the reinsurance premium, the primary will end up paying in advance for additional incurred losses.

Given that a moral hazard problem exists, we can use a little more structure to evoke a well known solution. Denote the primary insurer's profit (before any transaction costs of risk considered in section II) as $\Pi_P = \Pi_P(R, L, S, h) - a$. To account for the various costs of risk, I will assume that the insurer's value is a concave function of Π_P but I will also use the common device of assuming that value is separable in mitigation a.

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[5]This analysis establishes the optimal mitigation given the basis risk. For some problems the basis risk can be determined exogenously and this will require joint solution of mitigation and basis risk. The appropriate methodology is to estimate optimal mitigation as a functional relationship of basis risk; then to choose the value maximizing level of basis risk subject to the ex post optimization of mitigation.

(6) $V_P = \int U\{\Pi_P(R, L, S, h)\}f(L;a)dL - a$

Where f(L;a) is the conditional probability of observing losses L given mitigation level of a. Notice that U{.} resembles a utility function and concavity is analogous to risk aversion. However, here we mean that the various transaction costs of risk suggests that more risk yields lower value and thus a concave mapping of Π_P into V_P. The primary's optimal choice of "a" can now be represented by the following first order condition which is called the "incentive constraint".

(7) $\int U\{\Pi_P(R, L, S, h)\}f_a(L;a)dL = 1$

Now consider the optimal *ex ante* design of the reinsurance contract. To avoid unnecessary restriction of the problem, let the reinsurance premium R be a function of the revealed losses L (in other words, allow retrospective rating). Moreover, we can represent the comparative advantage of the reinsurer by assuming that it can diversify catastrophe risk and that it is effectively risk neutral. Designing an optimal policy now can be presented as a standard "principal-agent" problem. If the reinsurer (the principal) cannot directly monitor "a", it can choose to condition the premium, R, on the revealed value of L. With standard assumptions, the problem becomes one of minimizing V_P subject to the incentive constraint and a second (participation) constraint to ensure that the primary will actually purchase the contract offered. The solution is well known; *the optimal reinsurance premium R is a non decreasing function of the revealed loss L.*[6] The optimal design of the reinsurance contract is one with retrospective premiums.

The adaptation of the standard one period principal agent problem to the design of reinsurance yields retrospective premiums. The single period model has been extended to many periods[7] with the analogous result that the payment between the principal and the agent be related to prior losses (experience rating).[8] This prediction is testable, though casual observation of the reinsurance market suggests that it follows the model. While I am not aware of formal tests, long term relationships are normal in this market and it is common practice for poor claims experience against the reinsurer to be recovered in future premiums. This practice has been formalized over recent years with the introduction of finite reinsurance. By defining a fixed period, and limiting indemnity in relation to accumulated premiums, the reinsurance contract begins to look more like a debt instrument. But whether formally, or informally, setting reinsurance premiums to actual loss experience increases the degree of risk retained by the primary insurer; this additional retention being part of the cost of addressing the moral hazard.

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6 See Kreps chapter 16 for a presentation of this problem (not in a reinsurance setting) and for the necessary assumptions.

7 See Lambert (1986) (again not in a reinsurance setting).

8 The presence of long term contract and *ex post* rating can also be explained by other information problems. If information on which to base premiums is asymmetrically distributed, then prior rated contracts may not be closed. However, both parties may still gain from *ex post* rating, since this Bayesian update is observed equally by both parties.

Of course, reinsurers also can address moral hazard by increasing the resources devoted to monitoring the behavior of the ceding firms and conditioning the reinsurance coverage on this behavior. If reinsurers can monitor at low cost, then it will be more efficient to do so than to impose risk on the primary through *ex post* rating. In practice one would expect to see some monitoring and some rating. In this case, the costs of moral hazard would be incurred partly in monitoring cost, partly in imposing risk on the primary through *ex post* rating and, to the extent that these did not completely eliminate expropriatory behavior, partly through increased claims.

2. Alternative Risk Management Strategies For the Primary Insurer

The three principle risk management strategies identified for the firm were asset hedges, liability hedges and leverage management. This structure helps us to organize the instruments that are beginning to appear, but also it is useful to think through new strategies. In Figure 1 the three vertical shafts identify three types of risk for the primary insurer; these are not exhaustive but illustrative. First, consider asset hedge strategies. The obvious one is reinsurance and we can target this to catastrophe risk, other insurance risk, or possibly blanket coverage for all lines. Catastrophe risk also can be hedged by a catastrophe future of the type sold on the Chicago Board of Trade which will be discussed presently, but which is in effect a reinsurance policy sold by investors instead of reinsurers. The insurer can hedge its asset risk (i.e., risk on its stock and bond portfolios) by appropriate financial instruments such as stock options, interest rate futures, etc. Similarly, the insurer can cross hedge; i.e., choose to hold its reserves in financial assets that are positively correlated with insured losses. This is, of course, asset liability portfolio management.

Figure 1 also shows possible liability hedges. Liability hedges involve debt forgiveness should the loss experience be unusually large. Two such approaches can be distinguished according to who holds the debt. The insurer can issue debt to financial institutions or investors. When such debt contains a provision for forgiveness (principal, interest or both) on the basis of insured loss experience, then we shall call it a cat (catastrophe) bond or an "act of god" bond. But insurers, by their very nature, issue debt like instruments in the form of insurance policies. It is possible to include in this policy "debt" a forgiveness provision which reduces the amount payable to policyholders, depending on individual policyholder loss experience, the insurer's aggregate loss experience or the insurer's overall profits. One possible provision is to reduce the proportion of each individual's loss that is payable, as the insurer's aggregate loss rises. In a crude way, this is achieved by having different deductibles for cat loss and non cat loss. For example, it is usual practice to insure earthquake risk in California with a deductible that is a percentage of the property value; but to have no deductible for non catastrophe losses. We show this as "policy restrictions" in Figure 1 and focus the hedge on cat losses. A more direct hedging device it to require all policyholders to contribute higher premiums (or accept reduced policyholder dividends) if aggregate profitability falls. Indeed this is simply mutual insurance and mutual insurance is a liability hedge. Since pure mutualization gives the policyholder an equity stake in the whole insurance operation, we show "mutualization" as hedging risk in all three columns.

The third set of strategies involve leverage management. We will not dwell on these strategies in this section, since there is an extensive literature on the determination of appropriate leverage for insurers, much of it in Astin. Of course this wheel is important; I simply do not wish to re-invent it here.

2.a Asset Hedges:

Catastrophe Options

New types of catastrophe instruments are often explained in terms of the need to provide direct access to capital markets to supplement the limited capacity of reinsurance markets. Noting that catastrophe risk is not highly correlated with capital market returns, then the required rate of return to attract capital is the risk free rate. Current rates on line for reinsurance are sufficiently high to be able to beat the risk free rate [9] But this explanation is incomplete. If attractive investment opportunities are available to investors from shorting catastrophe risk, why is there not an influx of capital into reinsurance firms? It seems that high rates on line support the high transaction costs associated with reinsurance rather than excess returns to reinsurance shareholders. Thus, if new instruments are to compete successfully with reinsurance and to be attractive to investors, they must be designed to lower transaction costs. Moreover, since the dominant transaction costs is that due to moral hazard (excess losses, the additional costs of monitoring, and locking parties into long term relationships), then successful securitization of catastrophe risk, requires more effective ways of dealing with moral hazard. Also important is the ability of new instruments to address credit risk.

With reinsurance, the source of the moral hazard was the absence of basis risk. This can be seen by the term $\partial I/\partial L$ in equation 5. Since reinsurance is defined on the primary's loss L, then I=L and $\partial I/\partial L = 1$. This means that there is no basis risk and the third term in (5) operates to reduce the optimal level of mitigation. As the term $\partial I/\partial L$ gets closer to zero, there will be more basis risk, leaving (5) in the form $-\partial E(L(a))/\partial a \approx 1$. In this case, there would be little moral hazard and the primary would mitigate close to the social optimum. As we shall see, one of the main defining features of cat options, and some other new instruments, is their introduction of basis risk as a method of addressing moral hazard.

Catastrophe options are traded on the Chicago Board of Trade. The basic structure of these contracts is similar to other options and, except for the difference in basis risk, resembles stop loss reinsurance. The CBOT contracts are defined on various industry (mostly quarterly) indices of property liability losses. The indices are defined by region within the U.S. There is a national index, regional indices (Western, Midwestern, Southeastern, Northeastern and Eastern) and state indices (California, Florida and Texas). When index losses exceed the striking price, the contract pays the difference between the index value and the striking price. The basic instrument can be used to derive many trading strategies (spreads, strips, etc.) in much the same fashion as stock options.

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[9] See proposals by Guy Carpenter.

The effects of hedging with catastrophe options can be presented in the same formula used for reinsurance.[10] The trading strategy shown is a long position in a call. In equation 4, the term R(I; S) can be re-interpreted as the price of the option. Here "h" is the number of contracts purchased and C(I; S) is the payout on a standard contract on index "I" with strike price "S". However, since the insurer pays its own losses "L", but receives a payoff based on the chosen index "I", there is basis risk (L does not equal I). The size of the basis risk will vary. First, the insurer's own losses will contribute to the index, but for many insurers this will be modest. Second, to the extent that the primary has a portfolio similar to that of the other insurers comprising the index, the basis risk will be small. Indeed one would expect the hedging demand for CBOT options to be strongest for insurers with representative portfolios.

The major benefit of defining the option on the index, is that it controls moral hazard. The primary insurer that is able to practice *ex ante* or *ex post* mitigation, will receive much of the benefit of that activity in the form of reduced claims. However, this benefit will not be offset by a reduction in the payoff to the option, except to the limited extent that the primary's reduced losses affects the index. The idea can be illustrated by a simple example. Suppose that an insurer has a portfolio that represents 5% of the market covered by the index and correspondingly wishes to buy a call option that pays 0.05 times the payoff on the amount by which industry losses exceed "S". Since "I" is the sum of industry losses ($I \equiv \Sigma L_i$), then spending of "a_i" on safety by insurer "i" will reduce the index at the rate $\partial L/\partial a_i$. But since the primary is hedging only five percent of changes in the index, then the primary's payoff on its call position will be reduced only at the rate $(0.05)\partial L/\partial a_i$.[11] In contrast, spending on mitigation reduces the primary's own claims obligations to its policyholders at the full rate $\partial L/\partial a_i$. Thus, mitigation yields a large marginal net benefit to the primary (0.95 times $\partial L/\partial a_i$).

Catastrophe options face similar credit risk to reinsurance. Many financial instruments use "mark to market" to address credit risk. When the instrument is written on an underlying asset whose price evolves as a smooth process, "mark to market" offers considerable credit protection. This device prevents the build up of large liabilities. However, the temporal path of catastrophe insurance liabilities is anything but smooth. With storms, the lead time is, at most a few days. With earthquakes, the liability can change from zero to billions of dollars in one second. "Mark to market" is of little use. Sellers of catastrophe bonds are required to maintain a margin account. However, this device offers only limited protection unless the

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10 Other hedging strategies can be derived. One that offers some continuity with traditional reinsurance strategies is to buy a spread. This involves holding a call option with one striking price and selling another call with a higher striking price. The effect is to obtain a layer of hedge protection between a range of index losses. Apart from the fact that the loss is defined on the index, this arrangement is similar to layered reinsurance arrangements.

11 The same concepts can be described in the appropriate terminology. CBOT options are denominated in payment of $200 for every $100 million change in the index. Each $100 million in the index is referred to as a "point" Thus, the primary wishing to hedge for a 5% of the amount by which the index exceeded a chosen striking price, would purchase 25,000 units. Thus, if the strike price was 400 and the index was 450, the payoff on this position would be (450-400) times (200) times 25,000 = $250 million. Notice that $250 million is exactly 5% of the amount by which industry losses ($45 billion) exceed the strike price ($40 billion).

account is maintained at a level equal to (or close to) the maximum possible loss. Thus, catastrophe options impose some credit risk. The CBOT options offer a second line of defense. The CBOT maintains a security fund. However, the scale of this fund is fairly insignificant compared with the multi billion dollar liabilities that are plausible with these instruments. This is not to say that the credit risk is severe, only that it is potentially severe. The degree of credit risk depends on the spread of liability amongst investors who take short positions in these instruments. The point is that the structural design of this, and other asset hedges, introduces credit risk. As we shall see below, the structural design of the liability hedges avoids this problem.

2.b Liability hedges

Catastrophe Bonds

Debt forgiveness instruments go by several names; insurance linked bonds, Act of God bonds, catastrophe bonds and (anciently) bottomry. The idea is very old, dating to the medieval origins of insurance in Italy. A primitive arrangement was for merchants to fund ventures by borrowing to pay for the ship and/or cargo. However, in the event of the loss of ship or cargo, the debt would be forgiven. Thus, the lenders were "insuring" the vessel and its cargo. The idea has recently re-appeared. Recently, bond issues have been announced by insurers, that have forgiveness provisions in the event of catastrophic losses; the consideration being a higher interest rate. The generic design can allow for interest and/or principal forgiveness which can be total, partial or scaled to the size of the loss. Moreover, the forgiveness can be triggered either by catastrophic losses to the issuing firm, or to catastrophic losses measured on some composite index of insurer losses.

The effects of hedging with cat. bonds can be analyzed with equation (8). The insurer issues debt with a face value D which must be repaid with interest at a rate r. However, the debt can be forgiven (here I illustrate with the principal being forgiven not the interest) according to a loss index I. The forgiveness is shown by the term hC(I;S) which indicates that the cat bond is really a simple bond with an embedded call option written on the catastrophe loss.

$$(8) \qquad T \quad = \quad \{E+P+D\}(1+E(r_i)) - E(L(a)) - D\{1 - hC(I;S)+ r\} - a$$

The analysis of moral hazard is similar to that for asset hedges. Condition (9) below shows the first order condition for mitigation for the primary insurer which is identical to condition (5). The first term shows the effect of mitigation on the primary insurer's losses; the second term shows the increased marginal cost of mitigation; and the third term is the

$$(9) \qquad \frac{\partial E(T)}{\partial a} \quad = \quad -\frac{\partial E(L(a))}{\partial a} - 1 + h\frac{\partial C}{\partial I}\frac{\partial I}{\partial L}\frac{\partial L}{\partial a} \quad = \quad 0$$

effect of reduced mitigation (and therefore increased losses) on the cat bond forgiveness.

The interpretation of (9) depends on whether there is basis risk or not (i.e. whether I equals L). Consider that the cat bond is forgiven on the basis of the primary's own catastrophic losses, I=L. This moral hazard effect is similar to that under reinsurance. If the cat bond is forgiven dollar for dollar against the primary's own catastrophe losses, the primary has little, or no, incentive to control those losses. Controlling losses simply increases the amount of debt that must be repaid (the first and third terms would simply cancel out). With no cat bond, the primary would have reaped all the benefit of mitigation and would have chosen a level of mitigation at which marginal benefit equaled marginal cost.

Now if the cat bond is forgiven on the basis of some industry index of catastrophe losses, $I \neq L$, the moral hazard is similar to that for the catastrophe option. The primary spending on mitigation will only reduce the debt forgiveness to the extent of its share of the index. Thus, the primary contracting for forgiveness at the rate of 5% of the index (i.e., $5 of debt is forgiven for every $100 increase in industry losses) will reap a net benefit from mitigation equal to 95% of the reduction in its direct claims.

This analysis shows that cat bonds can be designed to achieve different balances between basis risk and moral hazard. Given freedom to select indices, the primary may well be able to identify some industry portfolio with similar exposure to its own. If it can, the basis risk from writing the cat bond on this index will be small, and the moral hazard problem will be largely mitigated. If the primary's portfolio is not represented well by a convenient industry loss index, then the hedging properties of an index based cat bond will be poor, even though moral hazard is addressed. In such circumstances, a cat bond based on the primary's own losses may be preferable with other controls (e.g. monitoring) used to address the moral hazard.

Cat bonds avoid the credit risk to the issuer, that is found with reinsurance or catastrophe options. Bondholders provide the hedge to the insurer by forgiving existing debt. Thus, the value of the hedge is independent of the bondholders' assets and the issuing primary insurer has no risk of non-delivery on the hedge. In essence, the cat bond is similar to a reinsurance contract in which the reinsurer opens a margin account equal to the maximum expected loss. Moreover, the primary insurer has access to the margin account. This avoids all possibility of default to the primary.[12]

A variation on the theme of debt forgiveness is the conversion of the debt into another asset, notably equity. This idea it to embody a conversion option in the debt, but the option is exercised by the issuer, not the bondholder. This can be called "reverse convertible debt" (RCD). A pure form for RCD is simply to permit the issuer to choose conversion at a fixed ratio of shares for bonds. When the share price falls, for whatever reason, the option will be "in the money". This instrument provides a partial hedge against a fall in share price and it does not matter whether the cause was a catastrophic loss or a fall in the value of the primary's asset portfolio. Doherty (1995) has shown that this instrument can be potentially useful for non insurance firms since it can be used to resolve incentive conflicts between

12 The risk to the bondholder is of interest. Had the primary issued a non forgiveness bond, it would have been subject to default risk. However, one of the most likely causes for default on such an issue would be that the primary insurer suffered catastrophic losses. What the cat bond does, is to turn the default risk (i.e. the implicit default put) into an explicit embedded option.

stakeholders and it avoids the transaction costs of bankruptcy. Indeed the resolution of these problems can be so effective that RCD has greater value than regular debt (i.e., the conversion option can have negative value). A more limited version of RCD for primary insurers could embody an event trigger; the conversion option can be exercised in the event of a defined catastrophe which could be based on firm losses or an index.

The value created for the primary on conversion is the difference between the outstanding debt obligation and the value of the equity used to redeem that obligation. Investors holding such bonds could well find them attractive despite their short position in the embedded option, since the conversion option carries more favorable incentives than the implicit default put in non-convertible debt. RCD may also be attractive to policyholders. I will note below the analogy between debt and the primary's policy liabilities. Drawing on this analogy, scaling the payout of policyholder claims to the size of a catastrophe, is equivalent to a mutual insurance in which scaling is achieved by policyholder dividends. There are strong theoretical and practical reasons why mutualization of catastrophe risk is an efficient form of risk sharing and there is a pressing case for considering contract design as part of a risk management program.

Policy Conditions and Mutualization.

Perhaps the most direct way in which the insurer can hedge its catastrophe risk is to require that the policyholder bear some of this risk. To explore this further, it is useful to take a small detour into the economics of insurance. Much of intellectual and lay thinking about insurance, focusses on an ideal in which the policyholder is fully insured for all loss. At an intellectual level, this ideal can be derived by assuming that policyholders are risk averse, but that all risk can be diversified by the insurer by holding a large portfolio of independent policies. The law of large numbers asserts that such a portfolio will leave the insurer with a highly predictable per policy average loss, and thus the competitive insurer will charge little, or no, risk premium. Being risk averse, individuals will fully insure since they can avoid risk without facing any significant loading of the premium above the expected value of loss.

With catastrophe risk, the law of large numbers is violated since losses are highly correlated. Thus, the insurer cannot rely simply on many policies to diversify its risk away. Moreover, if risk is costly to the insurer (why otherwise would we be discussing hedging strategies?), then the insurer would be forced to charge a risk premium and the optimal amount of insurance would be less than full coverage. It is important to understand that "optimal" reflects the interests of insurer and insured. The risk premium reflects the cost of risk bearing and this is a real social cost. The insured is better off having less insurance (and avoiding part of the risk premium) than being fully insured and facing the full risk premium. In short, the insured in trading off expected wealth against risk.

Now this reasoning can be refined in several ways following the seminal work of Karl Borch (1962), (which pre-dated and fully anticipated the capital asset pricing model). Where risk cannot be fully diversified, the optimal insurance arrangement from all policyholders' perspectives, is one in which all are full insured for idiosyncratic (read diversifiable) risk, but in which each shares in the social loss. This is tantamount to a mutual insurance arrangement; each policyholder is insured for catastrophe risk, but the proportion of insurance depends on the size of the catastrophe. In practice, this can be accomplished by a mutual which pays everyone's claim, but which reduces its dividend to all policyholders (or assesses them) by an amount related to total losses.[13]

The second way in which this reasoning can be refined is to address moral hazard between the policyholder and the primary insurer. This is closely related to the moral hazard occurring at the interface between the primary insurer and the reinsurer. For example, the *ex post* moral hazard that can arise between the primary insurer and reinsurer, stems from the lack of appropriate actions by the primary to prevent policyholders from "building up" claims or filing fraudulent claims. In short, the moral hazard that arises between primary and reinsurer is largely a "pass through" of the moral hazard between the policyholder and the primary. Policyholder moral hazard can be addressed by requiring that the policyholder share the loss, normally through the use of a deductible or policy limit (see Shavell 1979 and Stiglitz 1983). This idea has been extended by Smith and Stultzer (1994) who have shown that sharing risk through dividends also helps control moral hazard.

V. SECURITIZATION: MARKET ENHANCEMENT AND TECHNICAL EFFICIENCY

Securitization serves two general functions. First, securitization is market enhancing. Figure 2 shows the relevant properties of hedging instruments. The defining characteristic is its ability to control basis risk. Incidentally, hedging instruments can encounter moral hazard and credit risk. Securitization extends the range of choice in this three dimensional space. The figure shows the characteristics of the main instruments considered, but the point is that product design provides for continuous trade offs to be made across this space. The value of market enhancement arises because insurers are not identical. The issue can be simplified by considering the trade off between moral hazard and basis risk. In Figure 5, the line AB shows the potential choices available to the purchaser of a hedge; positions closer to A involve less basis risk and more moral hazard. The shape and position of line AB depends on technical issues and this will be discussed presently. Now, an insurer with a geographically diversified portfolio, may prefer to resolve moral hazard, not by reinsurance, but by accepting some basis risk by trading CBOT options (close to A on line AB). For this insurer, the basis risk will be fairly modest since its portfolio corresponds closely in structure to the "market portfolio" of insurance exposures. Another insurer with a more concentrated book of business, may find the basis risk in an available index to be unacceptable and will prefer reinsurance (close to B

13To argue that mutualization of this sort is "optimal" is often misunderstood. Policyholders would certainly be better off if they could fully insure at no risk premium. But this is not an option in a competitive market since investors would require that the insurer cover any cost of bearing undiversified risk. Thus the real choice for policyholders is (a) to have a policy with a large risk loading which would induce policyholders to accept a large deductible or coinsurance or (b) to accept a policy which covers idiosyncratic risk but which requires the policyholder to contribute in proportion to total losses. The argument here is that option (b) is better for policyholders than option (a). Notice that this argument is identical to the reasoning of the capital asset pricing model. In that model it is shown that the optimal investment strategy is for risk averse investors to hold a diversified portfolio (i.e., the market portfolio) such that each shares in the total market risk but each diversifies away idiosyncratic risk.

on line AB).

Market enhancement does increase efficiency, but the second function of securitization is to change technical efficiency. Consider the trade off between moral hazard and basis risk shown in Figure 3 as line AB. If this line can be shifted towards the origin, the efficiency loss from hedging will be reduced. To illustrate, note that reinsurance addresses this trade off in one of two ways. First a traditional reinsurance contract does not have basis risk, but bonds the parties in a long term relationship (and/or the primary is monitored) as a way of controlling moral hazard. By choosing the level of attachment for the reinsurance contract, the insurer can select a position on the AB line; higher retention involves more risk acceptance and less moral hazard. The second way is for the reinsurance contract to be restructured as a debt like instrument, as happens with finite reinsurance. This limits the hedging properties of the reinsurance contract (introduces basis risk) but does mitigate moral hazard. Now the primary has less incentive to let claims get out of control and less reinsurer monitoring is required. By changing the mix of debt and insurance in the finite risk plan, different points in moral hazard - basis risk space can be achieved. The question is now, which method involves the most efficient trade off; changing the reinsurance attachment point, or changing the insurance debt mix. Increasing efficiency means lowering the trade off line in Figure 3 from AB to CB.

Other options for increasing technical efficiency can be imagined. In a recent paper, John Major (1996) showed that, if insurers are allowed to hedge using a state wide index of industry loss experience, they can achieve significant reductions in volatility. But, state wide indices do involve some basis risk which will differ between firms according to their portfolio mixes. If indices were available for industry loss experience by zip code, then the basis risk could be reduced significantly. This reduction in basis risk arises partly because the insurer will be more concentrated, and have a larger market share, in some zip codes. Lowering the basis risk is achieved by increasing the hedge ratio in these high concentration zip codes. But this strategy will increase moral hazard, because the hedging insurer's losses comprise a significant portion of the industry losses in the zips. Now the technical question is this. Is it more efficient to use a state index and trade off moral hazard and basis risk with a fairly high hedge ratio; or should one use a zip code index and a lower hedge ratio? I.e., which strategy is depicted by line AB, and which by line CB?

Other possibilities for changing technical efficiency can be envisioned. For example, reinsurer monitoring is one method of controlling *ex post* moral hazard. Another is for the primary insurer to write direct contracts with appropriate incentives to policyholders for *ex post* loss mitigation (e.g. deductibles, coinsurance, retrospective premium adjustments). The rate at which moral hazard and basis risk can be traded off against each other with these two approaches may well differ for any insurer, and may well differ across insurers. The only safe conjecture is that there is no "one size fits all". It is this diversity that will permit value to be created through securitization, as insurers seek to find combinations of basis risk, credit risk and moral hazard that match their financial and organizational structure.

VI. SOME ACTUAL AND POTENTIAL STRATEGIES

Hedging by Primary Insurers

A straightforward use of the catastrophe instruments is for a primary insurer to replace, or supplement, reinsurance with cat options and bonds. Several insurers have made limited use of the traded CBOT catastrophe options though the size of this market is still modest (the size of the private market is unknown). Use of cat bonds is rarer. The most visible example lies in a recent USAA announcement for a $500 million dollar issue that would be forgiven on the issuer's own loss experience. As discussed, this strategy does not avoid moral hazard since the issuer's gain from reducing its losses is offset by a reduction in the debt under the cat bond. Moreover, unlike reinsurance where contractual relationships are set up to resolve incentive conflicts, the cat bond issue has no natural mechanism to combat moral hazard. Thus, investors will be looking for mechanisms that lie outside the terms of the issue to deal with moral hazard. Is the issue linked with other hedging instruments that provide appropriate monitoring? For example, does the issuer still have adequate conventional reinsurance in place, so that bondholders can "free ride" off the monitoring provided by the reinsurer. Alternatively, is the direct portfolio written with appropriate incentives (e.g. deductibles, dividends) to provide appropriate controls over policyholder moral hazard? This sort of investigation by potential purchasers goes somewhat beyond the normal credit monitoring required by prudent bond investors. The additional monitoring would be less crucial had the issue been based on an industry loss index, but this would introduce basis risk.

Providing Reinsurance Capacity

An alternative use for cat instruments is to enable the issue to extend reinsurance capacity. Many catastrophe reinsurers will seek to control risk by international diversification. It would be common for a specialty Bermuda catastrophe reinsurer to have a portfolio with risk in North and South America, Europe, Japan and the Antipodes. Such an insurer could issue bonds based on worldwide catastrophe risk to hedge its existing portfolio while maintaining an acceptably low level of basis risk. Taking this approach further, the bond issue could also provide the basis for extending its capacity to offer reinsurance to primaries. This thinking seems to lie behind a recent cat bond issue announced in Geneva in August 1996 by the American International Group (A.I.G.). This issue provides for scaled forgiveness of debt, according to the number of catastrophes recorded in the publication Sigma (published by the Swiss Re.). The index is based on five regions across the world and a catastrophe is defined as industry losses above a set value that varies according to the region. The debt is progressively forgiven and will be completely forgiven with five events within the operational period. A.I.G. intention appears to be to use this issue to offer retrocessions to catatrophe reinsurers.

An expression that is now sometimes heard in connection with this type of activity is "intermediating basis risk". The idea is this. A reinsurer with a wide spread of business can write a hedge contract based on a very broad index without assuming a high level of basis risk. Were a primary with a much less diversified portfolio to write a hedge using the same index, the basis risk would be very high. Thus, the reinsurer "intermediates the basis risk" by hedging on the index and using this hedge to expand conventional reinsurance to primaries. This should be viewed with a little caution. By absorbing the basis risk and offering conventional reinsurance, all the moral hazard issues in the reinsurer-primary relationship remain. This type of activity can expand capacity, but does not address the moral hazard problem. Thus, the potential to add value, depends on which explanation for financial innovation is valid. If innovation simply addresses a diversification problem, the intermediating basis risk can potentially add capacity and add value. If innovation is needed to respond to moral hazard and similar frictions, then intermediating basis risk does nothing to address the root cause.

The California Earthquake Authority

In an attempt to increase the availability of earthquake insurance, the State of California has formed the California Earthquake Authority. The state initiative includes provisions that permit insurers to offer earthquake insurance with appropriate limitations of coverage, (such as deductibles and limited coverage on house contents), and a financial structure to "reinsure" the industry in the event of a very large loss. The structure includes potential assessments on policyholders and various layers of financing including reinsurance. Of particular interest is a bond layer of $1.5 billion with interest forgiveness. The principal is secured by using a portion of the proceeds of the issue to purchase U.S. Treasury strips. The interesting feature of this initiative is that it combines many of the features discussed in this paper. Policyholders are required to participate both in their individual losses and in the collective loss. Moreover, the issue of interest forgiveness cat bonds allows insurers to supplement conventional reinsurance hedges with cat bonds.

Facilitating Third World Investment

Other uses can be imagined. Insurance is rarely bought on private dwellings in the third world even though many regions are subject to severe catatrophe risk. However, development banks such as the World Bank who often lend to these countries for the construction of industrial and infra-structure projects, seem to be showing increasing concern about possible default following catastrophic events. A plausible hedging scenario could jointly address this default risk and the need for mitigation. Loss mitigation is usually most cost effective at the point of construction. Development bank loans could be used to fund projects with embodied mitigation. If this issue is made as a catastrophe bond, the development bank could use the additional interest to purchase a catastrophe option designed to repay interest and principal in the event of a defined disaster. Thus, unlike normal cat bonds in which the option is embedded, the option could be stripped out and sold separately. Such a scheme jointly addresses the hedging issue and loss prevention. Moreover, by linking with project finance, mitigation can be introduced at the point of construction of the asset when it is most cost effective. The trick in designing an operation scheme would be to define the trigger to minimize *ex post* moral hazard on the part of the borrowing government. For their part, those shorting the cat call could conceivably partly hedge their exposure in exchange rate futures which are likely to be highly sensitive to the triggering event.

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