MICKEY MOUSE AND MORAL HAZARD: UNINFORMATIVE BUT CORRELATED TRIGGERS*

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ABSTRACT

Holmström has argued that multiple signals can be used to redress moral hazard only if the additional signals are informative of the agent's hidden action. Additional signals are now being used in insurance securitizations that have the opposite function; they are uninformative of the policyholder's action, but they are correlated with the loss. We rework the principal agent model to examine these triggers. We will also illustrate how the Oriental Land Company, owners of Tokyo Disneyland, as well as many insurance companies, are using these triggers and how they are now being embodied in executive compensation contracts.

KEYWORDS: basis risk, index based contracts, moral hazard, securitization

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1. INTRODUCTION

Insurance and related markets have recently witnessed a surge of innovative contract designs that redress moral hazard. Typical is a hedge contract known as a catastrophe bond recently issued to cover the earthquake risk to the Disney theme park near Tokyo. A traditional insurance contract pays to the policyholder the economic loss she has suffered; this is called an *indemnity trigger*. In contrast, the Disney contract uses a so called *parametric trigger*; the payout is based on a formula which uses the intensity, location and depth of the quake. Since these parameters are correlated with the actual loss, the contract offers a noisy hedge, or more technically there is some basis risk. The second feature of this parametric trigger is its objectivity; it cannot be manipulated by the agent's actions, and so the level of loss mitigation selected by the agent should be largely unaffected by the hedge contract. In short, there is little or no moral hazard.

The Disney contract is typical of many recent hedge programs where an insurance policy is supplemented with a hedge featuring a second, parametric, trigger. The use of multiple triggers to resolve principal agent problems is well known. In a simple principal agent model, output carries information on the agent's hidden action and, to align incentives, the agent is required to bear some output risk (examples are management compensation based on profit and insurance policies with a deductible). Holmström (1979) shows that the optimal compensation to the agent also can be related to additional variables if these signals carry additional information on the agent's action, i.e. if the variable is *informative of the action*. For example, the manager's compensation might be based on staff turnover, bond ratings, etc., as well as on profit.

But the trigger used in the Disney contract plays a very different role from that anticipated by Holmström. Like many other insurance policies and quasi insurance instruments known generically as insurance linked securities, the Disney triggers were selected precisely because they carried no information on the agent's actions.[1] Rather, the triggers were chosen because they are correlated with the output (in this context the policyholder's loss). We will rework the basic moral hazard model to address such *non-informative-but-correlated* triggers.[2] We will then illustrate how such triggers are being used in the insurance market and the wider capital market for insurance linked securities.

We can provide some prior intuition on alternative uses of additional triggers. Consider an insurance policy covering damage to buildings from events such as earthquakes or hurricanes. The policyholder is able to influence the amount of damage caused by these events. *Ex ante* actions include strengthening construction of the building and the securing of the building to foundations. *Ex post* actions would include protection of already damaged property from weather and thieves. Since inspection of actions is costly, policies might have a co-payment to give the policyholder an incentive to mitigate. Suppose that a second, low cost, signal is available that carries additional information on the likelihood of mitigation; e.g. policyholder's financial leverage or credit score. In Holmström's model, the policy payout should be adjusted to the credit score only if is informative. But if credit score carried no

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[1]This statement is not strictly true. The parametric description of the event cannot influence pre loss actions of the agent. Moreover, since post loss actions cannot influence the payout on the contract, the agent will still be inclined to mitigate. However, it is possible that the level of mitigation might vary with the magnitude of the event. For example, larger events might be accompanied by more publicity about post-loss mitigation opportunities. In this case, the parametric description of the event may contain some information about post-loss actions. Smith and Stultzer (1995) examine this issue.

[2] Terminology presents some challenges here. When Holmström talks of "informative" he means "informative of the agent's action". However, his definition of "informative" is broader and can include the case I which the signal is correlated with output or loss. We will use definitions consistent with Holmström's in Section 3 below.

information on the likelihood of mitigation, its inclusion in the contract would (a) not improve incentives and apparently (b) expose the policyholder to more risk.

Consider the statement that use of a second signal will increase risk, but will not improve incentives if the signal is uninformative of the action. Under what conditions would this statement be true? Adding the second signal introduces a second source of risk in the agent's payoff and this would certainly increase the agent's overall risk if the two risks were independent. But whether the overall risk to the agent increases depends on the correlation. Because of its correlation with the dollar (or yen) earthquake loss, triggers such as Richter scale and location hedge the policyholder's loss reasonably well and therefore provide a reasonable substitute for the conventional indemnity trigger. Switching at the margin from a manipulable indemnity trigger to an objective parametric trigger preserves incentive for the policyholder to invest in loss mitigation. The parametric trigger substitutes a (noisy) hedge which does not discourage mitigation, for an indemnity hedge that does - it trades off basis risk for moral hazard.

2. SOME EXAMPLES OF UNINFORMATIVE BUT CORRELATED TRIGGERS IN INSURANCE

While Holmström (1979) examines the control of moral hazard through the use of additional signals that are informative of the policyholder's action, but implicitly are uncorrelated with the insured loss, we will examine the orthogonal case where the second trigger is uninformative but correlated. In this section, we will give examples, old and new, of such insurance arrangements.

Illustrative of a new marketplace that has arisen recently for insurance linked securities is the catastrophe bond issued to hedge the earthquake risk of Tokyo Disney facility.[3] The risk to the facility is hedged by issue of bonds whose principal and/or interest can be forgiven in the event of an earthquake.[4] The hedge comes in the form of a reduction in debt to a counter-party rather than a cash settlement from the counter-party. The debt is not issued to provide working capital; rather its purpose is to provide collateral for the hedge transaction. If the event occurs, then the issuer simply does not have to repay the debt in full. The relief of the debt is scaled to a parametric description of the earthquake; its magnitude, location and depth. These parameters are totally outside the control of the owner. Accordingly, the owner will reap the full benefits from any investments made in protecting the property from earthquake damage. Indeed these triggers were chosen precisely because they preserve the incentive for the owner to protect his property. This contrasts with the traditional insurance indemnity payment where the benefits of protection are externalized to the insurer.

This transaction is fairly typical of many catastrophe bond issues made in the last three or four years.[5] Mostly these bonds have been issued to protect the natural catastrophe risk of insurance companies whose underwriting portfolio exposes them to potentially large claims. Traditionally, the excess risk has been reinsured with other insurance firms on an indemnity basis. However, this type of reinsurance does encounter significant moral hazard since the benefits of protective actions by the primary insurer are externalized to the reinsurer.[6] Insurers have usually used these catastrophe hedges in addition to reinsurance rather than as an outright substitute. Thus, their overall hedge programs of these reinsurance firms comprises a

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[3] See National Underwriter, May 24th 1999.
[4] The bond issue is fronted through a special purpose vehicle.
[5] For a summary of this market see Froot (1999).
[6] Evidence of moral hazard costs in reinsurance transactions is provided by Doherty and Smetters (2000).

conventional insurance trigger and a second trigger which is correlated with, but outside their control.

Catastrophe bonds issues do vary in significant respect. Perhaps the most important for our purposes is in the nature of the trigger. In addition to the parametric trigger, other types of triggers have been used to redress moral hazard.[7] Many insurance bonds scale the payout to an index trigger. For example, the reinsurer Lehman Re recently used such a trigger in a cat bond issued to hedge against California earthquake risk. The index is the aggregated insured catastrophe losses of all insurers operating within some defined location. Indices have been assembled on a state, regional, or national basis. The correlation between the individual insurer's losses and the index depends on the firm's market share, and how representative of the market is its book of business. For example, if the market share is small but the firm's book has a geographical spread representative of the market, then the correlation will be high. But the small market share suggests that the individual insurer's loss reducing actions will have a trivial impact on the indexed losses. Thus, an indexed hedge will introduce modest basis risk, but provide a significant relief of moral hazard costs. Notice that the typical hedge comprising a policy and a cat bond offer an indemnity trigger and a *long* position in the index.

The combination of an indemnity policy and an index trigger resembles a mutual, or participating, insurance contract. Mutual insurance is as old as insurance itself. Many mediaeval marine insurance contracts were mutual compensation schemes; if one of a number of participating merchants lost a ship or cargo, the remainder would contribute to paying for the loss. Today, a large part of the insurance market is organized on mutual basis, and some non mutual firms issue participating policies. The payout under mutual and participating policies comprises two parts; an indemnity and a dividend. The individual is compensated for any loss suffered but also receives a dividend (or pays an assessment) based on the aggregate loss experience of the portfolio of policies held by the insurer. Since the dividend paid to the policyholder is negatively related to the insurer's aggregate loss, the mutual comprises an indemnity and a *short* position in the index.

Various explanations have been offered for mutual insurance.[8] Most relevant is Smith and Stultzer (1995) who show that aggregate losses of a pool of policyholders might offer an informative signal of post-loss actions taken by an insured to mitigate loss. For example, after a hurricane approaches or strikes a location, policyholders can take actions to mitigate the loss (shuttering windows, placing a canvas over a hole in the roof). Since these actions are conditioned on the occurrence of the loss, they can be informative in the Holmström sense.

Our interest in mutuals is orthogonal to that of Smith and Stultzer. They show that a mutual policy will help redress moral hazard if the index offers a second informative signal. The mutual achieves this by combining an indemnity and a short position in the index. When a mutual offers a signal that is uninformative of the agent's action but is correlated with the agent's loss, then it can be used as a second trigger. However, in this case, the hedge comprises an indemnity and a long position in the index. Finally while Smith and Stultzer

[7]Another device used recently is a modeled trigger. A computer model is constructed to estimate the economic impact on a firm of various events such as storms and earthquakes. Once the model is constructed and parameterized, the hedge contract is written. If an event occurs, the model is run with the event parameters to produce an estimate of the loss to the firm. The hedge contract pays this estimate, rather than the actual economic loss.

[8]Some explanation do not deal with policyholder moral hazard. Starting with Borch (1962), various writers have argued that mutual insurance provides optimal risk sharing arrangement between risk averse parties when risk are correlated. Mayers and Smith (1986, 1988) have shown that mutual forms of organization are sometimes efficient at controlling expropriatory behavior of owners and managers. These papers do not deal with expropriatory behavior of policyholders which is our focus here.

address only *ex post* moral hazard, our results can apply both to *ex ante* and *ex post* moral hazard.

3. OPTIMAL RISK SHARING RULES WITH MULTIPLE TRIGGERS

Since the illustrations we will use later are insurance or related ones, we will set up the principal agent problem as an optimal insurance problem. For our purposes, it makes little difference whether we allow any consumer surplus to be retained by the policyholders or accrue to the insurer, so we will arbitrarily choose the competitive case. The policyholder starts with initial wealth w_0 but is exposed to the possibility of a loss y. A second trigger x is also observed by both parties. The joint cumulative distribution function (CDF) and probability density function (PDF) of x and y are denoted $\Phi(x, y; a)$ and $j(x, y; a)$, respectively, where a is an action of the policyholder. We assume throughout that there is moral hazard so the joint distribution depends on a.

The following maximization program is examined[9]:

(1) $$\underset{s(.,.),a}{Max} \int\int u(w_0 - y + s(x, y)) j(x, y; a) dxdy - v(a)$$

subject to conditions

(2) $$\int\int s(x, y) j(x, y; a) dxdy = 0$$

(3) $$\int\int u(w_0 - y + s(x, y)) j_a(x, y; a) dxdy - v'(a) = 0 ,$$

where u is the policyholder's utility function, with $u' > 0$ and $u'' < 0$, and v is his separable cost of action. Equation (2) is the zero expected profit constraint or participation constraint and equation (3) is the incentive compatibility constraint. The problem is solved by using Kuhn-Tucker conditions for $s(x, y)$ for all (x, y). The first-order conditions are

(4) $$u'(w)[1 + gh(x, y; a)] + m = 0 \quad \forall (x, y)$$

(5) $$m \int\int s(x, y) j_a(x, y; a) dxdy + g\left\{\int\int u(w) j_{aa}(x, y; a) dxdy - v''(a)\right\} = 0 ,$$

where $h(x, y; a) = j_a(x, y; a) / j(x, y; a)$, $w = w_0 - y + s(x, y)$, m and g are the Lagrangian multipliers associated with constraints (2) and (3), respectively.

Differentiating equation (4) with respect to y and x, respectively, yields

(6) $$s_y(x, y) = 1 + T_u(w) \frac{gh_y(x, y; a)}{1 + gh(x, y; a)}$$

(7) $$s_x(x, y) = T_u(w) \frac{gh_x(x, y; a)}{1 + gh(x, y; a)} ,$$

where $T_u(w) = -u'(w)/u''(w)$ is the policyholder's index of absolute tolerance towards risk and $g > 0$ if we assume $v'(a) > 0$ and $\Phi_a \leq 0$ (Holsmtröm 1979).

[9] The first-order condition for the incentive compatibility constraint is assumed to be appropriate (Jewitt 1988).

Definition 1 (Holmström 1979). *A signal x is said to be uninformative when $h_x(x, y; a) = 0$ for all x and y, and informative otherwise*

We need to be careful about terminology and definitions. In using the expression "informative" Holmström is thinking about whether the signal carries information about the agent's action. However, his definition is broader and can apply to a signal that carries no information about the action but is correlated with the loss. To be consistent with Holmström's terminology we will say that a signal can be "(un)informative of the action" and/or "(un)informative of the loss". The latter term means that the signal is (in)dependent of the loss.. We now decompose the signal along these lines.

The joint PDF of $(\tilde{x}, \tilde{y})$ can be written as

(8) $j(x, y; a) = f(y / \tilde{x} = x; a) g(x; a)$,

where f is the PDF of $\tilde{y}$ conditional on $\tilde{x} = x$ and g is the PDF of $\tilde{x}$. The ratio h can thus be rewritten as

(9) $h(x, y; a) = h^c(x, y; a) + h^i(x; a)$,

where $h^c(x, y; a) = f_a(y / \tilde{x} = x; a) / f(y / \tilde{x} = x; a)$ and $h^i(x; a) = g_a(x; a) / g(x; a)$. The ratio h^i represents the impact of a on the PDF of $\tilde{x}$. The ratio h^c characterizes the correlation between y and x. From this decomposition, the definition of an informative signal provided by Holmström is reconsidered and, consequently, the following definitions are suggested.

Definition 2. *The signal x is said to be uninformative of the action when $h_x^i(x; a) = 0$ for all x, and informative of the action otherwise.*

Definition 3. *The signal x is said to be uninformative of the loss when $h_x^c(x, y; a) = 0$ for all x and y, and informative of the loss otherwise.*

If the signal is uninformative of both the action and the loss, then it is uninformative according to Holsmtröm's definition.

From the first-order condition (7) and Definition 1, the optimal risk sharing contract will depend on the signal x if, and only if, it is informative. This is a simpler way of proving Holmström's Proposition 3.[10] Likewise, the following proposition is derived from equations (7) and (9), and definitions 1 and 2.

Proposition.

(i) *If the signal x is uninformative of the loss, it will (not) be part of the optimal risk sharing contract if, and only if, it is informative (uninformative) of the action.*

(ii) *If the signal x is uninformative of the action, it will (not) be part of the optimal risk sharing contract if, and only if, it is informative (uninformative) of the loss.*

[10] It is easy to demonstrate that this holds when the principal is risk averse.

This proposition has the reasonable interpretation given in the introduction. If a second signal increases risk to the agent without yielding more information on the agent's hidden action, then it is inefficient to embody that signal in the contract.[11] On the contrary, if the signal is uninformative of the action but informative of the loss, then it will be used to reduce the agent's risk without deterioration of incentives.

The following corollary shows that a signal is uninformative of the action if, and only if, its marginal distribution is independent of the action. The first part of the previous proposition is thus reinterpreted.

Corollary 1. *If the signal x is uninformative of the loss, then x will not be part of the optimal contract if, and only if, its distribution is independent of a:* $g_a(x;a)=0$ *for all* x.

Proof:

($\Leftarrow$) obvious from Definition 2 and the Proposition.

($\Rightarrow$) $h_x^i(x;a)=0$ implies that there exists a function t such that $g_a(x;a)/g(x;a)=t(a)$. Since g is a PDF, it satisfies $\int g_a(x;a)dx=0$. This implies that $t(a)=0$, i.e. $g_a(x;a)=0$ for all x.

When the signal x and the loss y are stochastically independent, it trivially follows from Definition 3 that the signal is uninformative of the loss. But the reverse does not hold: a signal that is correlated with the loss could be uninformative of the loss. In other words, the independence assumption is a sufficient condition for a signal to be uninformative of the loss, but this is not necessary condition. However, the following corollary shows that the independence assumption is also a necessary condition for the linear exponential family, a large parametric family that includes many of the well-known distributions (exponential distribution, Poisson distribution, normal distribution…). The second part of the Proposition can thus be rewritten as follows.

Corollary 2. *Suppose that the PDF of* $\tilde{y}$ *conditional on* $\tilde{x}=x$ *belongs to the linear exponential family. If the signal* x *is uninformative of the action, then* x *will (not) be part of the optimal contract if, and only if, x is independent of (correlated with) the loss y.*

Proof:

The distribution of $\tilde{y}$ conditional on $\tilde{x}=x$ is one of the linear exponential family if it is expressed as

[11]This qualification of Holmstrom is closely related to Jewitt (1988). He replicates Holmstrom's analysis with the restriction that the principal is risk neutral. In the non insurance structure used by Jewitt, the principal is endowed with *y* and contracts for the payoff *-s(x,y)*. If the principal is risk neutral, any change in risk from adding the contract to the principal's portfolio has no consequence. Thus, no uninformative signal can enhance efficiency. The interpretation requires modification in the insurance example, since the endowed position in output *y* is held by the agent (the policyholder) who seeks the insurance contract to hedge that position. The equivalent interpretation of Jewitt for the insurance contract would be that additional uninformative signals cannot enhance efficiency if the agent is risk neutral. Of course, it is because the agent is risk averse that she seeks insurance in the first place.

(10) $$f\left(y/\tilde{x}=x;a\right)=\frac{p(y)e^{-l(x,a)y}}{q(l(x,a))}$$

where q is a normalizing constant. We have

(11) $$h^c(x,y;a)=-l_a(x,a)\left[y+\frac{q'(l(x,a))}{q(l(x,a))}\right],$$

which implies that

(12) $$h_x^c(x,y;a)=-l_{ax}\left[y+\frac{q'}{q}\right]-l_a l_x\frac{q''q-q'^2}{q^2}.$$

Consequently, $h_x^c(x,y;a)=0$ for all x and y i.f.f. $l_a(x,a)=0$ and/or $l_x(x,a)=0$. Since the distribution of y depends on *a*, we must have $l_x=0$. From equation (10), this means that y and x are independent.

If the signal is uninformative of the action and uninformative of the loss, then from the Proposition, the optimal risk sharing rule does not depend on it. Equivalently, the signal is uninformative and, from Holmström's Proposition 3, it is not part of the optimal contract. However, the optimal rule could only depend on the loss if the signal is informative of both the action and the loss, as shown in the following corollary.

Corollary 3. *Suppose that the ratios h^i and h^c satisfy*

(13) $h_x^i(x;a)=-h_x^c(x,y;a)$ *for all x and y.*

Then the signal x will not be part of the optimal risk sharing contract.

Proof: If condition (13) is true, equation (7) collapses to zero implying that s_x is zero.

Thus, we have a special case where x is informative of the action and informative of the loss, but is not part of the optimal risk sharing rule.

This case may be a curiosity but it helps to summarize this section. The case for including a second trigger, x, in the optimal contract rests in two effects. First, as Holmström (1979) rightly pointed out, the additional trigger can carry additional information on the agent's hidden action. The second reason is that the additional trigger can act as a proxy for the policyholder's loss. If the second variable is uncorrelated with the loss, a necessary (and sufficient) condition for its use is that it is informative of the action. If the second trigger is not informative of the action, a necessary (but not sufficient) condition for its inclusion is that it is correlated with the loss. Thus one can reduce risk to the agent without a deterioration of incentives. These two effects are not additive but opposing. If x is informative of the action and correlated with the loss, the positive incentive are offset by increased risk. Equation (13) establishes the very special case where these two offsetting effects cancel out.

The explicit form of the optimal risk sharing rule can be derived under the assumption of constant absolute risk aversion (CARA). If the agent's preferences exhibit CARA, then the index of absolute tolerance is constant and satisfies $T_u(w) = 1/A$ for all w, where A is the index of absolute risk aversion. Solving equations (6) and (7) as a system of differential equations yields

$$(14) \qquad s(x,y) = y + \frac{1}{A}\ln[1 + gh(x,y;a)] + \text{constant} .$$

Corollary 3 provides condition on the ratio h under which the optimal risk sharing rule depends only on the individual loss y. We derive now conditions under which y is not part of the optimal risk sharing contract.

Corollary 4. *Suppose that the policyholder's preferences exhibit constant absolute risk aversion and that a function* b *such that the ratio* h *can be written as:*

$$(15) \qquad h(x,y;a) = -\frac{1}{g} + b(x;a)e^{-Ay} ,$$

where A *is the index of absolute risk aversion. Then the loss* y *will not be part of the optimal risk sharing rule.*

Proof: Introducing equation (15) in equation (6) leads to $s_y(x,y) = 0$.

Corollaries 3 and 4 thus define conditions under which the optimal risk sharing contract depends only on the individual loss y or on the signal x, respectively.

4. ILLUSTRATING THE CHOICE OF TRIGGERS IN A MEAN VARIANCE MODEL

Mean-variance model. We will highlight choices of trigger using mean variance analysis. The policyholder's final wealth is

$$(16) \qquad \tilde{w} = w_0 - \tilde{y}(a) - a + b\tilde{y}(a) + \tilde{a}x(a) - aE\tilde{x}(a^*) - bE\tilde{y}(a^*),$$

where a and b are the hedge ratio on x and y, respectively, and a^* is the anticipated choice of the action by the policyholder after the policy has been purchased. These contracts are assumed to be sold at a fair price. If the variance and covariance terms are invariant with respect to the action and a higher level of effort reduces the expected loss, i.e. $\partial E\tilde{y}(a)/\partial a < 0$, then it can be shown (see the Appendix) that the optimal hedge ratios are:

$$(17) \qquad a^* = \frac{1}{1-r^2}\frac{g}{2ls_x}\left[\frac{\partial E\tilde{x}(a)/\partial a}{s_x} - r\frac{\partial E\tilde{y}(a)/\partial a}{s_y}\right],$$

$$(18) \qquad b^* = 1 + \frac{1}{1-r^2}\frac{g}{2ls_y}\left[\frac{\partial E\tilde{y}(a)/\partial a}{s_y} - r\frac{\partial E\tilde{x}(a)/\partial a}{s_x}\right],$$

where s_x is the standard deviation of the index, s_y is the standard deviation of the loss, $r \equiv \mathrm{cov}(\tilde{x},\tilde{y})/(s_x s_y)$ is the coefficient of correlation assumed to be nonnegative and less than unity, $g > 0$ is the Lagrangian multiplier associated with the incentive compatibility constraint, and l is the measure of the policyholder's aversion towards risk. In the mean-variance framework, the signal x is informative of the loss if $r \neq 0$, and uninformative of the loss otherwise. The signal is informative of the action if $\partial E\tilde{x}(a)/\partial a \neq 0$, and uninformative of the action otherwise. The proposition derived in the expected utility model can be reinterpreted in the mean-variance model using equation (17). If the signal is uninformative of the action, the optimal hedging position of the index contract is long, $a^* > 0$, i.f.f. $r > 0$. It is not part of the optimal risk sharing rule, $a^* = 0$, i.f.f. it is not correlated with the loss. If the signal is uninformative of the loss, the optimal hedging position is long (short) i.f.f. $\partial E\tilde{x}(a)/\partial a > (<) 0$. It is not part of the optimal risk sharing rule i.f.f. the signal is uninformative of the action. Under the following condition:

$$(19) \qquad \frac{\partial E\tilde{x}(a)}{\partial a} = r\frac{s_x}{s_y}\frac{\partial E\tilde{y}(a)}{\partial a},$$

the signal is informative of both the action and the loss, but it is not part of the optimal hedging strategy, $a^* = 0$. Corollary 3 is thus illustrated in this mean-variance model. Likewise, if

$$(20) \qquad \frac{\partial E\tilde{y}(a)}{\partial a} = r\frac{s_y}{s_x}\frac{\partial E\tilde{x}(a)}{\partial a} - (1 - r^2)2l\frac{s_x s_y}{g},$$

then, $b^* = 0$. The optimal hedging strategy does not require a coverage on the individual loss. This illustrates Corollary 4 in the mean-variance model.

In this section, we will illustrate this process of selecting a signal that is informative of the loss using the natural catastrophe insurance market. As a concrete example, consider an insurer wishing to hedge its exposure to hurricane losses (i.e., claims from its own policyholders) in the Southeast United States; specifically Florida, Georgia and South Carolina. This insurer has a 5% market share of this three state region. However, its book of business is not evenly spread but concentrated within certain zip codes in this three state region.

Consider three possible choices for the signal or trigger variable x. First, consider a parametric trigger, denoted x_1, comparable to that used in Tokyo for Disney. In this case, the trigger is hurricane of given magnitude directly hitting any of the zip codes within Florida, Georgia and South Carolina in which the insurer has a concentration of business. The second trigger, x_2, is an index reflecting the aggregate losses within the tri-state region of all insurers. The third index, x_3, is a weighted average of the loss indices of all insurers in only those zip codes in which this insurer has a concentration of business. By construction, the insurer will form a significant portion of this index.

Parametric triggers. The first trigger, x_1, does not encounter moral hazard in usual natural catastrophe hedges.[12] The parameters describe the naturally occurring event such the intensity, and location of a storm, the number of inches of rain falling, the height of flood. These

[12] Though it is feasible that parametric triggers can encounter moral hazard in other applications. For example, an oil company recently sought to hedge its pollution risk with a contract that scaled the payoff to the number of barrels of oil spilled. This trigger is effective in countering ex post moral hazard since it gives the firm an incentive to clean up after a given spill. But it is less effective for ex ante moral hazard.

parameters are outside the control of the parties to the hedge contract. We can represent this by stating that the trigger is not a function of a safety investment a, i.e., $x_1 \neq x_1(a)$.

Besides the Disney cat bond, various other contracts have used parametric triggers. For example, a mutual insurer, Kemper, recently engaged in a securitization deal to cover its risk from earthquakes on the New Madrid fault which could be triggered by an earthquake of 5.0 or higher on the Richter scale occurring in one of seven Midwest states.[13] Moreover, in the developing market for weather derivatives, the typical objective triggers are "inches of rainfall" or temperature measures such as "heating days" and "cooling days".

Index triggers. The two index triggers, x_2 and x_3, differ in their effectiveness at hedging risk and also in the degree of moral hazard. To examine the trade off between moral hazard and basis risk in such indices, consider a stylized example of index construction. The index comprises the actual losses of n insurers whose losses are identically distributed with risk, s_y, and the correlation of losses between any pair of insurers is r. Since we are discussing natural catastrophe losses, r is positive and quite high. The index is

$$(21) \qquad x = \sum_{i=1}^{n} y_i \,.$$

In addition, we assume that actions a_i affect the expected loss of insurer i but have no impact on the loss of other insurers. With these simplifications,

$$(22) \qquad \frac{\partial E\tilde{x}}{\partial a_i} = \frac{\partial E\tilde{y}_i(a_i)}{\partial a_i}.$$

The variance of the index is

$$(23) \qquad s_x^2 \equiv \operatorname{var}(\tilde{x}) = s_y^2 n[1+(n-1)r],$$

and the correlation between the index loss and insurer loss is

$$(24) \qquad r \equiv \frac{\operatorname{cov}(\tilde{x}, \tilde{y}_i)}{s_x s_y} = \sqrt{\frac{1+(n-1)r}{n}}\,.$$

We can now restate the solutions for the hedge ratios on x and y, in terms of the correlations between constituents of the index, r, and n which measures the (inverse) of the share of this insurer in the index. For example, n is larger for the aggregate index, x_2, than for the zip code index, x_3. Equation (17) becomes

$$(25) \qquad a^* = -\frac{\partial E\tilde{y}(a)}{\partial a}\frac{g}{2l}\frac{1}{s_y^2}\frac{r}{(1-r)}\frac{1}{[1+(n-1)r]},$$

and the derivatives with respect to n and r are:

$$(26) \qquad \frac{\partial a^*}{\partial n} = \frac{\partial E\tilde{y}(a)}{\partial a}\frac{g}{2l}\frac{1}{s_y^2}\frac{r^2}{(1-r)}\frac{1}{[1+(n-1)r]^2} < 0,$$

$$(27) \qquad \frac{\partial a^*}{\partial r} = -\frac{\partial E\tilde{y}(a)}{\partial a}\frac{g}{2l}\frac{1}{s_y^2}\left\{\frac{1}{(1-r)}\frac{1}{[1+(n-1)r]}\left[\frac{1}{1-r} - \frac{(n-1)r}{1+(n-1)r}\right]\right\} > 0.$$

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[13] National Underwriter, April 5, 1999.

Similarly, we deduce from equation (18) that

$$(28) \qquad b^* = 1 + \frac{\partial E\tilde{y}(a)}{\partial a}\frac{g}{2l}\frac{1}{s_y^2}\frac{1}{(1-r)},$$

and clearly

$$(27) \qquad \frac{\partial b^*}{\partial n} = 0$$

$$(28) \qquad \frac{\partial b^*}{\partial r} = \frac{\partial E\tilde{y}(a)}{\partial a}\frac{g}{2l}\frac{1}{s_y^2}\frac{1}{(1-r)^2} < 0.$$

The signs of these derivatives are appealing. Recall that the average correlation between individual members and the index, r, roughly tracks the correlation between the index and the insurer's loss, r. So when the available index becomes more informative of the loss, i.e. higher r, the insurer will increase his hedge ratio on the signal x and reduce his reinsurance on the loss y. However, the impact of the size of the index is a little more complex. First, recall that n is a measure of the scale of the insurer relative to the index (effectively the insurer's market share in the index). The level of insurance on loss y, b, is not affected by the relative size of the index n. However, the hedge ratio for the second trigger x, a, will fall with n. This naturally reflects scale; like a small investor buying an index fund, a small insurer will only wish to hedge a small portion of the aggregate market risk. However, hedging only a small fraction of the aggregate market loss encounters little moral hazard. Thus, taking a small position in a highly aggregated index is efficient since it allows the insurer to supplement his partial hedge on y with an incremental hedge on x that has minimal moral hazard.

Putting these thoughts together, the ideal index is one where the insurer has a small market share, thus low moral hazard, but the index is still highly correlated with the insurer's loss; i.e., a high correlation r and a high size of the pool n. Such an index is uninformative of the action and informative of the loss. Unfortunately the ideal index might be difficult to find. Cummins, Lalonde and Philips (2000) suggest that the more aggregated index also tend to have greater basis risk, i.e. lower r, than indices compiled at the zip code level. This suggests that many real choices of indices face the trade off between *high* r *low* n or *low* r *high* n.[14] Moreover, the catastrophe options traded on the Chicago Board of Trade offer both national and regional indices. Index triggers are also used in U.S. crop yield insurance where the payout to the farmer is based on area yield.

Choosing a trigger. The choice of triggers for our illustrative Southeast Insurance firm can now be stated: x_1 is uninformative of the action but relatively informative of the loss; x_2 is relatively uninformative of the action and moderately informative of the loss; x_3 is more informative of the action and more informative of the loss.

The contract choices are depicted in Figure 1. The initial wealth position of the insurer is shown as E. If only the x risk is hedged by means of a cat bond, the insurer can attain position x_1, x_2 or x_3, depending on which trigger is used. For example, with trigger x_1, there is no moral hazard and increasing the hedge ratio to move from E towards x_1 will not

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[14] However, their work does indicate that for many insurers, even indices compiled at the state level have a reasonably high correlation with their losses.

involve any loss of expected wealth. However, since x_1 is not perfectly correlated with y, there is significant basis risk remaining. With trigger x_2, there is modest moral hazard which is anticipated in the price of the index hedge. Thus, the line $E - x_2$ shows small loss of wealth as the hedge ratio increases towards position x_2. There is also considerable basis risk, more here than with x_1. Trigger x_3 has more moral hazard and less basis risk than x_2.

The remaining part of the risk hedge is the coverage on the basis risk. So for example with trigger x_2, the insurer can attain any position on the segment $x_2 - C$ by varying the deductible on the reinsurance policy. Position C shows full coverage. The choices of trigger can now be shown. The parametric trigger x_1 clearly dominates the more aggregated index x_2. No such dominance relationship exists between the parametric trigger and the zip code index x_3. Thus, the choice between these would rest on risk preference with x_3 preferred by the more risk averse insurer.

5. OTHER PRINCIPAL-AGENT PROBLEMS

Executive compensation. The application of correlated but uninformative trigger to insurance can be explained as follows. The original purpose of the contract is to transfer risk from the risk-averse policyholder to the less risk-averse insurer. But, to control incentives for loss mitigation, the policy forces some risk back onto the risk-averse policyholder in the form of a deductible or other coinsurance provision. A second, parametric or index trigger, permits the policyholder to hedge the deductible position. Thus, contracts can be designed with the policyholder bearing more of the y risk since the increased volatility can be offset by an increased stake in the x risk.

We examine now how this can be applied to other principal agent problem. Consider executive compensation. Normally, an incentive compensation requires the agent (the manager) to take a long position in the firm’s stock to provide appropriate incentives. But this increases risk on the supposedly risk-averse manager. Indeed as Hall and Liebman (1998) have shown, executives are subject to enormous volatility. Can a second trigger now be used to reduce this volatility without diluting incentives?

This issue has been identified by Abowd and Kaplan (1999) as one of their burning issues facing compensation design. An obvious candidate for a second trigger is a short position in a market index.[15] This index is beyond the control of the individual manager, but is likely to have a reasonable positive correlation with the firm’s stock price. This effectively extracts out the market risk, which is outside the manager’s control, from the manager’s long stock position and leaves him or her only with idiosyncratic risk, which is more within the manager’s control. One structure for such a compensation plan is that the manager is given a combination of securities; long stock and short market indices. Another is to build these triggers into the terms of a stock option issue. This can be done by scaling the strike price of the stock option to an appropriate index (see Johnson and Tian, 2000). This practice could have avoided all the fortuitous wealth transfer to executives from the recent bull market and left them with earnings that more closely reflected their actions.

[15] The choice of indices involves the same issues discussed for cat bonds. A national market index such as Dow Jones, will be almost completely uninformative of the action and moderately informative of the risk (the beta risk). However, if the firm has a large market share of a given industry, use of that industry stock index as a second trigger will be relatively informative of the action and higher informative of the loss.

Contingent fees for plaintiffs' lawyer – a counter-example. The typical executive compensation problem involves a trade off between risk sharing and efficiency. The principals (the shareholders) are diversified and have a comparative advantage in risk bearing over undiversified managers. The benefit of the second trigger is that it can reduce risk to the manager while still providing incentives.

This contrasts with the typical relationship between the plaintiff and his lawyer. The normal compensation is a contingent fee whereby the lawyer is paid only a portion of the damage award (if any). While this fee structure exposes the lawyer to considerable risk in any one suit, the typical lawyer handles several (many) cases and can thus spread risk. In contrast, the plaintiff is exposed to considerable risk which is not easily diversified. This implies there is no trade off between risk sharing and efficiency. Placing more risk on the lawyer improves both risk sharing and incentives. Thus, in contrast to executive compensation, there is no case here for use of a second trigger that is uninformative of the lawyer's action but correlated with the damage award.

6. Conclusion

Relating our results to Holmström's (1979) classic paper has been a little tricky. On the one hand, his main proposition appears to contradict our analysis. He states that additional triggers only will be part of the optimal contract design if they are informative of the agent's action. This is fine if the signals are independent of the output. However, his formal definition of "informative" is broader than he allows verbally, and encompasses both "informative of the action" and "informative of the loss" (roughly correlation). By decomposing signals were are able to analyze an important class of moral hazard controls that are being increasingly used in the insurance and, possible, compensation markets.

The use of informative (of the action) but correlated triggers in insurance has been limited largely to naturally occurring events such as earthquakes and weather. While the occurrence of such events (so called frequency risk) is beyond the control of individuals, the economic impact (severity risk) is not. Mitigation can reduce the severity of given events. By linking the payout to objective trigger and disassociating it from the economic impact, moral hazard is controlled.

The use of such triggers is now being explored in other areas where the "frequency risk" is more manipulable. For example, an oil company wishing to supplement its insurance for liability from oil-spills, has explored a contract where the trigger is the number of barrels of oil spilled rather than monetary loss. Similarly, many valuables such as antiques and artworks are insured for a fixed value. While such triggers do not avoid ex ante moral hazard (the occurrence is controllable), they do address ex post moral hazard. These triggers are not as clean as those used for Disney. But they do illustrate that insurance players are searching for secondary triggers that strike a balance between the competing concepts of "informative of action" and "informative of loss". In insurance language, they trade off moral hazard and basis risk.

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APPENDIX

The expectation and the variance of the policyholder's final wealth expressed in equation (16) are, respectively:

(A1) $E\tilde{w} = w_0 - (1-b)E\tilde{y}(a) + aE\tilde{x}(a) - a - aE\tilde{x}(a^*) - bE\tilde{y}(a^*)$

(A2) $\text{var}(\tilde{w}) = (1-b)^2 s_y^2 + a^2 s_x^2 - 2a(1-b)\text{cov}(\tilde{x}, \tilde{y})$.

In the mean-variance model, the policyholder maximizes the objective function

(A3) $V \equiv E\tilde{w} - l \ \text{var}\,\tilde{w}$

where l is the measure of his aversion towards risk. The ex post choice of the action is solution to

(A4) $\frac{\partial V}{\partial a} = -(1-b)\frac{\partial E\tilde{y}(a)}{\partial a} + a\frac{\partial E\tilde{x}(a)}{\partial a} - 1 - l\left[(1-b)^2\frac{\partial s_y^2}{\partial a} + a^2\frac{\partial s_x^2}{\partial a} - 2a(1-b)\frac{\partial\,\text{cov}(\tilde{x},\tilde{y})}{\partial a}\right] = 0$.

The optimal hedge ratios are solution to the maximization problem:

(A5) $\underset{a,b}{Max}\,V \quad s.t.\ \partial V/\partial a = 0$.

The first-order necessary conditions with respect to the decision variables a and b are, respectively:

(A6) $g\frac{\partial E\tilde{x}(a)}{\partial a} - 2l\left[a s_x^2 - (1-b)\text{cov}(\tilde{x},\tilde{y}) + ag\frac{\partial s_x^2}{\partial a} - (1-b)g\frac{\partial\,\text{cov}(\tilde{x},\tilde{y})}{\partial a}\right] = 0$

(A7) $g\frac{\partial E\tilde{y}(a)}{\partial a} - 2l\left[-(1-b)s_y^2 + a\,\text{cov}(\tilde{x},\tilde{y}) - (1-b)g\frac{\partial s_y^2}{\partial a} + ag\frac{\partial\,\text{cov}(\tilde{x},\tilde{y})}{\partial a}\right] = 0$,

where $g > 0$ is the Lagrangian multiplier associated with the constraint (A4). The following properties are assumed in order to simplify the above equations. The variance and covariance terms are invariant with respect to the action:

(A8) $\frac{\partial s_x^2}{\partial a} = \frac{\partial s_y^2}{\partial a} = \frac{\partial\,\text{cov}(\tilde{x},\tilde{y})}{\partial a} = 0$;

a higher level of effort reduces the expected loss:

(A9) $\frac{\partial E\tilde{y}(a)}{\partial a} < 0$.

Under assumption (A8), solving the system of equations (A6) and (A7) yields to equations (17) and (18).

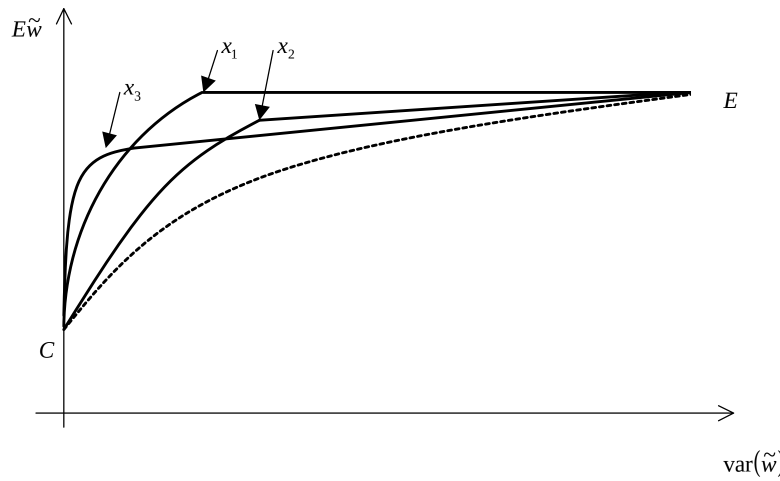

Figure1. Choice of signal.