

**A Firm Can Only Go Bankrupt Once  
Risk Management Strategies in an Uncertain World\***

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**July, 2002**

\* Earlier versions of this paper have been presented at the Workshop “Organizational Encounters with Risk” at the London School of Economics (LSE) May 3-4, 2002 and the Risk Symposium “Formulating Policy to Deal with Contemporary Environmental Risks” at Ohio State University (OSU) on May 13, 2002 . We appreciate the helpful comments by Jim Ament and Paul Kleindorfer as well as those participating in the LSE workshop and OSU symposium. We acknowledge support for this research from the U.S. Environmental Protection Agency under Cooperative Agreement C R 826583 with the University of Pennsylvania, the Wharton Risk Management and Decision Processes Center, the Columbia University Earth Institute and the National Science Foundation.

## ABSTRACT

The World Trade Center terrorist attacks of September 11<sup>th</sup> have stimulated us to think about the challenges organizations face in dealing with low-probability events that have catastrophic consequences. More specifically, there are certain bad events that can only occur once. Death is the clearest example: an individual's death is irreversible and unrepeatable. With respect to firm behavior, bankruptcy is the obvious analog.

This paper develops a framework for addressing the issue of *interdependent security* (i.e. when the protective decisions by one division affects the risks faced by others) and its relationship to catastrophic events that can cause bankruptcy. We show that when failure to take actions by any division can bankrupt the entire firm, the economic incentive for any division in an organization to invest in risk-reduction measures depends on how it expects the other divisions to behave in this respect. For this class of problems there may be situations where no one invests in safety measures, even though everyone would be better off if each division had incurred this cost.

To encourage the adoption of security measures in these situations one needs to turn to institutional coordinating mechanisms and/or public-private partnerships. The paper focuses on two such approaches: (1) how a firm encourage its divisions to invest in protection through internal rules and (2) the role that government regulations coupled with third party inspections and insurance play in encouraging investment in protection. The concluding section explores areas for future theoretical and empirical research in interdependent security.

## 1 Introduction

The World Trade Center terrorist attacks of September 11<sup>th</sup> have stimulated us to think about the challenges organizations face in dealing with low-probability events that have catastrophic consequences. More specifically, there are certain bad events that can only occur once. Death is the clearest example: an individual's death is irreversible and unrepeatable. With respect to firm behavior, bankruptcy is the obvious analog. This paper explores the impact that the possibility of an extreme event such as bankruptcy has on the propensity of different parts of an organization to take risks.

A key point to emphasize at the outset is that the economic incentive for any division in an organization to invest in risk-reduction measures depends on how it expects the other divisions to behave in this respect. Consider Division 1. If it thinks that the other divisions will not invest in protection then this reduces Division 1's incentive to do so. On the other hand should Division 1 believe that the others are taking appropriate steps to mitigate their risks, then it may be best for Division 1 to do so as well. In other words there may be situations where no one invests in protection, even though all divisions would be better off if they had incurred this cost. As will be shown this situation does **not** have the structure of a prisoners' dilemma game, even though it has some similarities.

The fundamental question that motivates our research is: "Do organizations, such as chemical firms, airline companies and decision-makers such as computer network managers, invest in security to a degree that is adequate from either a private or social perspective?" In general the answer is No. We will then explore the obvious next question: "What should we do about this?"

### 1.1 Common Features of the Problem

There are several different versions of this problem and all have certain features in common. We have already indicated one of these: a payoff that is discrete. A bad event either occurs or it does not, and that is the full range of possibilities. You die or you live. A firm is bankrupt or not. A plane crashes or it doesn't. It is not useful in these examples to differentiate the outcomes more finely.

Another feature common to the problems that we consider is that the risk faced by one agent depends on the actions taken by others. In other words there are externalities. The risk that a corporate divisional manager faces of his company being sent into bankruptcy depends not only on how he manages his divisional risks but also on how other division heads behave. The risk of an airline's plane being blown up by a bomb depends on the thoroughness with which other airlines inspect bags that they transfer to this plane.

Finally there is a probabilistic element in all of these situations. In contrast to the standard prisoners' dilemma paradigm where the outcomes are specified with certainty, the interdependent security problem involves chance events. The question addressed is whether to invest in protection when there is some probability, often a very small one,

that there will be a catastrophic event that could be prevented or mitigated. The risk depends in part on the behavior of others. The unfavorable outcome is discrete in that it either happens or does not.

## 1.2 Importance of Problem Structure

These three factors – non-additivity of damages, dependence of risks on the actions of others, and uncertainty– are sufficient to ensure that there can be an equilibrium where there is underinvestment in risk-prevention measures. The precise degree of underinvestment depends on the nature of the problem. We focus here on the possibility of bankruptcy of a firm due to a catastrophic loss to one of its plants or divisions.

An example would be a Bhopal-like accident to a chemical plant where the losses are so large that it causes bankruptcy to the entire operation. Another example is an ownership group such as Lloyd's which controls a number of syndicates all operating in a semi-autonomous fashion. If one of the syndicates experiences a severe enough loss it can lead the ownership group to declare bankruptcy. Recently Arthur Anderson was sent into bankruptcy by the actions of its Houston branch. Several years ago Barings was likewise destroyed by the actions of a single trader in its Singapore division.

In each of these cases we had multi-unit organizations in which the risk of bankruptcy faced by any unit was affected by its own choices and by the choices made by other units. In such a situation the incentive that any unit has to reduce bankruptcy risks is lessened by the knowledge that others are not doing so. A culture of risk-taking can spread through the organization because knowledge that a few groups are taking risks reduces the incentives that others have to manage them carefully.

As noted above, there can be a stable equilibrium where all agents choose not to invest in risk reduction measures, even though all would be better off if they did invest. An interesting property of some of these equilibria is the possibility of *tipping* as described by Schelling (1978). More specifically how can we ensure that enough agents will invest in security so that all the others will follow suit?

## 2 Characterizing the Problem

We now set out formally the framework within which we study interdependent security (henceforth denoted IDS) utilizing chemical plant protection as an illustrative example. We first investigate the two agent problem and then extend this to multiple agents.

### 2.1 Chemical Plant Protection: The Two Agent Problem

Consider two identical independently operating divisions in the BeSafe chemical firm:  $A_1$  and  $A_2$ , each maximizing its own expected returns and having to choose whether to invest in a protective measure. Such an investment would reduce the probability of a catastrophic chemical accident to one of its plants. Let  $p$  be the probability of an accident that bankrupts the division and  $q \leq p$  be the probability that the accident

bankrupts the entire firm. Note that  $q$  and  $p$  are not independent of each other. The loss from an accident to the participants in the division is  $L$ . One should view  $L$  as the costs that managers and other employees of the division will incur if their division goes bankrupt. These include the search costs for new employment and other negative features associated with losing ones job including loss of reputation.<sup>1</sup> The expected loss from such a catastrophic accident to the participants in the division is thus  $pL$ . If the division has invested in protective measures at an upfront cost of  $c$ , then the chances of this accident is reduced to zero.<sup>2</sup>

Suppose Division 1 has invested in protection. There is still an additional risk  $q$  that BeSafe will go bankrupt if Division 2 has not taken this precautionary measure. In other words, the employees in Division 1 may lose their jobs because of the carelessness of Division 2. In this sense Division 2 can contaminate other parts of the organization by **not** protecting its plants against a catastrophic accident. Similarly Division 1 can contaminate Division 2 if it fails to adopt adequate protection.

Let  $Y$  be the assets of each division before any expenditure on protection or any losses during the year from the risks faced. Employees in each division are assumed to receive bonuses at the end of the year that are proportional to the size of the division's ending assets. The cost of investing in security is  $c < Y$ .

Assume that each division has two choices: invest in security, **S**, or do not invest, **N**. Table 1 shows the expected returns to the two divisions for the four possible outcomes:

**Table 1: Expected Returns Associated with Investing and Not Investing in Security**

		<i>Division 2 (A<sub>2</sub>)</i>	
		<b>S</b>	<b>N</b>
<i>Division 1 (A<sub>1</sub>)</i>	<b>S</b>	$Y-c, Y-c$	$Y-c-qL, Y-pL$
	<b>N</b>	$Y-pL, Y-c-qL$	$Y-[pL + (1-p)qL], Y-[pL + (1-p)qL]$

The rationale for these expected returns is straightforward. If both divisions invest in security (**S,S**), then each incurs a cost of  $c$  and faces no possible catastrophic accidents so that each of their net returns are  $Y-c$ .

If  $A_1$  invests and  $A_2$  does not (**S,N**), then  $A_1$  incurs an investment cost of  $c$  but there is still a chance  $q$  that a catastrophic accident will occur in  $A_2$  causing BeSafe to go bankrupt so that  $A_1$ 's expected loss from damage originating elsewhere is  $qL$ . This

<sup>1</sup>See Greenwald and Stiglitz (1990) for a discussion of a further discussion of the costs of bankruptcy that professional managers in firms suffer should the firm go bankrupt.

<sup>2</sup> We have assumed the risk to be zero to simplify the exposition. The qualitative results do not change if there is still a positive probability of an accident with a loss of  $L$  after precautionary measures have been adopted.

expected loss represents the *negative externality* imposed by  $A_2$  on  $A_1$ . In this case  $A_2$  incurs no cost of protecting itself and faces no risk of bankruptcy from  $A_1$ , but does face the risk of damage originating in one of its plants with an expected loss of  $pL$ . The lower left payoffs (**N**, **S**) are just the mirror image of these.

Suppose that neither division invests in protection-- (**N**, **N**) in Table 1. Then each has an expected return of  $Y - pL - (1-p)qL$ . The expected losses can be characterized in the following manner. The term  $pL$  reflects the expected loss originating from an accident in ones own division. The second term reflects the expected loss from an accident originating at the other division that bankrupts the firm ( $qL$ ) and is multiplied by  $(1-p)$  to reflect the assumption that bankruptcy to a division can only occur once. In other words, the risk of contamination only matters to a division when that division does not have a catastrophic accident originating at home.

Since each division wants to maximize the expected returns to its own employees, the conditions for it to invest in protection against a catastrophic accident are that  $c < pL$  and  $c < p(1-q)L$ . The first constraint is exactly what one would expect if BeSafe consisted of a single division: that is, the cost of investing in protection must be less than the expected cost to its employees from a catastrophic accident. Adding a second division tightens the constraint by reflecting the possibility of contagion. This possibility reduces the incentive to invest in protection. Why? Because in isolation, investment in protection buys the employees in the division freedom from bankruptcy. With the possibility of contagion it does not. Even after investment there remains a risk of bankruptcy emanating from the other division. Investing in protection buys you less when there is the possibility of contamination from others.

This solution concept is illustrated below with a numerical example. Suppose that  $p = .1$ ,  $q = .05$ ,  $L = 1000$ ,  $c = 98$ . The matrix in Table 1 is now represented as Table 2.

**Table 2: Expected Returns Associated with Investing and Not Investing in Security**  
**Illustrative Example:  $p = .1$   $q = .05$ ,  $L = 1000$  and  $c = 98$**

		Division 2 ( $A_2$ )	
		<b>S</b>	<b>N</b>
Division 1 ( $A_1$ )	<b>S</b>	$Y-98, Y-98$	$Y-148, Y-100$
	<b>N</b>	$Y-100, Y-148$	$Y-145, Y-145$

One can see that if  $A_2$  has protection (**S**), then it is worthwhile for  $A_1$  to also invest in security since its expected losses will be reduced by  $pL = 100$  and it will spend 98 on the security measure. However, if  $A_2$  does not invest in security (**N**), then there is still a chance that  $A_1$  incurs a loss. Hence the benefits of security to  $A_1$  are only  $p(1-q)L = 95$  which is less than the cost of the protective measure. So  $A_1$  will **not** want to invest in protection. In other words, either both divisions invest in security or neither of them does so. These are the two Nash equilibria for this problem.

## 2.2 The Multi-Agent IDS Case

The results for the two-agent IDS case carry over to the most general settings with some increase in complexity. The incentive for any agent to invest in protection depends on how many other agents there are and on whether or not they are investing. Other agents who do not invest reduce the expected benefits from one's own protective actions and hence reduce an agent's incentive to invest. In this section we review briefly the main features of the general case, without providing detailed proofs of the results. Those can be found in Kunreuther and Heal (2002) and Heal and Kunreuther (2002).

Suppose there are now  $n$  identical divisions. Each has a probability  $p$  of a catastrophic accident that can cause bankruptcy to the division and  $q \leq p$  that the accident bankrupts BeSafe if it does **not** invest in security systems. This probability is zero if it invests. If a division does not invest in protection then it can create negative externalities to all the other divisions. Let  $X(n, j)$  be the total expected negative externalities imposed on a division which has invested in security when  $j$  of the other  $n-1$  divisions have also taken this step.

If none of the other divisions are protected, then the condition for any division to invest in protection is given by the following condition:  $c < p[L - X(n, 0)]$ . If all the other divisions are protected, then there are no negative externalities imposed on the division that has also protected itself. (i.e.  $X(n, n-1) = 0$ ). Let  $c^*$  be the value of  $c$  where the division is indifferent between investing and not investing in protection when  $j$  of the other divisions have invested in security. In other words  $c^* = p[L - X(n, j)]$ . If there are no negative externalities because all the divisions have invested in security, then  $c^* = pL$  which is the same as if the division were operating in isolation. As more divisions do not invest in protection then  $c^*$  decreases, so that the division is less likely to take security measures if it is maximizing the expected returns of its employees.

Now suppose that the number of divisions ( $n$ ) in the organization gets large. When none of the other  $n-1$  divisions invest in protection then the negative externalities to a division that has installed protection can be shown to approach  $X(n, 0) = L$ .<sup>3</sup> This implies that the expected loss to any division approaches  $L$  as a result of contamination from all the other unprotected divisions. In this situation  $c^* = 0$  and there is no cost incentive for any division to invest in protecting itself against a catastrophic accident.

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<sup>3</sup> In general we show in (K-H 2002) that

$$X(n, 0) = qL \sum_{i=0}^{n-2} [(1-q)^i] = [1 - (1-q)^{n-1}]L$$

As  $n$  approaches  $\infty$  then

$$X(n, 0) = qL / [1 - (1-q)] = L$$

Here is the intuition for this somewhat surprising result. If one division is unprotected, then if it incurs a catastrophic accident, there is a probability  $q$  that the firm will go bankrupt. One weak link in the organization compromises all the other divisions. In other words, one unprotected division endangers all of the other divisions in the firm even if they have all invested in security. The more divisions that have not invested in protection the greater the chances that the employees of any division will be looking for another job even if its own plants are secure from a catastrophic accident. As more divisions decide not to invest in security (i.e. take action **N**), the probability of a catastrophic accident gets very large and there is no economic incentive for your division to undertake protection. In the limit this probability approaches 1 and  $c^*=0$ .

### 3 Proposed Risk Management Solutions for the IDS Problem

The above example suggests that there are limited economic incentives for divisions in firms to invest in protection against low probability events that could bankrupt their company if they believe that other divisions in their organization will **not** do so. In this section we examine the following two questions:

- How can a firm encourage its divisions to invest in protection through internal rules?
- What role can government regulations coupled with third party inspections and insurance play in encouraging firms to invest in protection?

#### 3.1 Internal Organizational Rules

In a large firm with many divisions there is likely to be a need for some type of coordinating mechanism from top management if each division's objective is to maximize the expected returns of its own employees. A key question in this regard is how companies who advertise that "*Safety is our most important product*" operationalize this slogan.

A natural way for it to deal with this situation is to form a centralized management committee (CMC) that specifies a set of rules requiring each division to take measures that make sense from the firm's point of view. In their classic book on the behavioral theory of the firm Cyert and March (1963) noted that organizations normally develop a set of standard operating procedures to guide the actions of different divisions or groups.

In the context of the above example, the CMC of BeSafe could institute a specific rule that would require the division to invest in any protective measure where the expected benefits to the firm exceeded the costs of the measure. In an  $n$ -division firm, total assets prior to investing in protection are  $nY$ . Hence if a catastrophic accident occurred, the loss to the firm would be  $nY$ . Hence the expected benefits from investing in protection would be  $p(nY)$ . In this case, the CMC could require each division to invest in protection if the total costs of the protective measure was  $nc < p(nY)$  or  $c < pY$ . This simple rule effectively

eliminates the negative externalities that might otherwise discourage a division from investing in protection.

If the firm wanted to maximize its expected returns then it would also forbid divisions from investing in protection if  $pY < c < pL$ . In this situation the division would have an incentive to invest in safety measures because of a concern with the losses to its employees should the firm go bankrupt; however, this action would not be cost-effective from the vantage point of the firm.<sup>4</sup>

A less intrusive way of encouraging investment in protective measures is to provide subsidies to divisions when  $c < pY$  and the division would otherwise not invest in safety. The challenge for the CMC is to determine the appropriate subsidy to give a division and to find appropriate sources for these funds.

### **3.2 Role of Third Party Inspections, Insurance and Regulations**

If divisions within firms are reluctant to adopt protective measures to reduce the chances of catastrophic accidents there may be a role for government standards and regulations. One reason for involving the public sector is that some of the consequences of a chemical accident will affect nearby residents but the industrial facility will not be held fully liable for these impacts. For example, suppose there are decreases in property values to homes in the surrounding area or there are disruptions in community life because of an accident. The firm causing the accident will not be legally responsible for these losses.

One way for the government to enforce its regulations is to turn to the private sector for assistance. More specifically, third party inspections coupled with insurance protection can encourage divisions in firms to reduce their risks from accidents and disasters. Such a management-based regulatory strategy shifts the locus of decision-making shifted from the regulator to firms who are now required to do their own planning as to how they will meet a set of standards or regulations. [Coglianese and Lazer (2001)]

The passage of Section 112(r) of the Clean Air Act Amendments (CAAA) of 1990 offers an opportunity to implement such a program. This legislation required facilities to perform a hazard assessment, estimate consequences from accidents and submit a summary report to the U.S. Environmental Protection Agency (EPA) called the Risk Management Plan (RMP) [Belke 2001]. The challenge currently facing the EPA is how to encourage compliance of these regulations so that firms will be operating in a safer manner than they otherwise would be.

There is some urgency for a type of decentralized procedure with appropriate incentives due to the EPA's limited personnel and funds for providing technical guidance and auditing regulated facilities. Chemical firms, particularly smaller ones, have little financial incentive to follow centralized regulatory procedures if they estimate that the likelihood they will be inspected by a regulatory agency are very small and/or they know the fine should they be caught will be low. In such cases they may be willing to take their

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<sup>4</sup>We thank Ravi Aron for pointing this out to us.

chances and incur the fine should they violate the existing rule or regulation and be caught.

The combination of third party inspections in conjunction with private insurance is a powerful combination of two market mechanisms that can convince many firms of the advantages of implementing RMPs to make their plants safer and encourage the remaining ones to comply with the regulation to avoid being caught and fined. The intuition behind using third parties and insurance to support regulations can be stated rather simply. One of the biggest concerns of the EPA is that it doesn't have enough resources to audit all firms and their divisions subject to the RMP rule. Low-risk divisions, who the EPA has no need to audit, cannot credibly distinguish themselves from the high-risk ones without some type of inspection.

By delegating part of the inspection process to the private sector through insurance companies and third parties, the EPA provides a channel through which the low-risk divisions in firms can speak for themselves. If a division chooses not to be inspected by third parties, it is more likely to be a high-risk rather than a low-risk one. If it does get inspected and shows that it is protecting itself and the rest of the organization against catastrophic accidents it will pay a lower premium than a high-risk division which is not undertaking these actions. In this way the proposed mechanism not only substantially reduces the number of inspections the EPA has to undertake, but it also makes their audits more efficient.

Kunreuther, McNulty and Kang (2002) show more formally how such a program could be implemented in practice. They provide supporting evidence from pilot studies undertaken in Delaware and Pennsylvania whereby the Department of Environmental Protection in these two states worked closely with the insurance industry and chemical plants in testing out the proposed program.<sup>5</sup>

The centralized management committee of a firm should support this program for two reasons. It gives them a rationale for hiring third party inspectors from outside to make sure their divisions are operating in a safe manner. It also increases the firm's expected profits by reducing the negative externalities that divisions create due to their fear of being contaminated by others.

#### **4 Extending the Analysis**

The choice as to whether to protect against events where there is interdependence between your actions and those of others raises a number of interesting theoretical and empirical questions. We discuss some of these in this concluding section of the paper.

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<sup>5</sup> For more details on these pilot studies see McNulty et al (1999) and U.S. Environmental Protection Agency (2001).

## 4.1 Tipping Behavior

Suppose that divisions in a company are heterogeneous so that they have different risks and costs associated with their activities. In the case of a chemical firm some divisions may be responsible for plants that have a much higher risk of a large-scale accident than plants operated by other divisions. In an investment banking firm the trading division is likely to take more risks with their activities than the mergers and acquisition division. The actions taken by Nick Leeson and the traders he hired at the Barings Futures Singapore office were primarily responsible for bringing down Barings bank.<sup>6</sup>

In Heal and Kunreuther (2002) we have shown that there may be one division in the firm occupying such a strategic position that if it changes from not investing to investing in protection, then all others will find it in their interests to follow suit. And even if there is no single division that can exert such leverage, there may be a small group. More specifically the division that creates the largest negative externalities for others in the firm should be encouraged to invest in protective behavior not only to reduce these losses but also to induce other divisions to follow suit.

This type of *tipping* behavior is in the spirit of the many interesting examples described in Schelling (1978) where there is a sudden change from one equilibrium to another due to the movement of a few agents (e.g. the sudden change in the racial composition of a neighborhood). Tipping behavior implies that one needs to focus on only certain parts of an organization to convince others that it is in their economic interest to follow suit. It suggests that it is particularly important to persuade some key players to manage risks more carefully. Working with them may be a substitute for working with all the divisions in the firm.

## 4.2 Principal-Agent Problems

A key aspect of the IDS problem is that it is difficult to motivate individuals or groups to take certain actions that are in the best interest of the firm should others decide **not** to follow suit. This raises a set of challenges for aligning the incentives between the principal (e.g. a firm) and its agents (e.g. the divisions in the firm). The most obvious way to encourage these divisions to invest in protection is to utilize either formal rules promulgated by a centralized management committee (CMC) of the firm or through regulations from a government agency such as the EPA.

The standard principal-agent models discussed in the literature are predicated on the use of economic incentives to agencies so they will undertake specific actions that are in the best interest of the firm. Multi-agent versions of the principal-agent problem assume there is interdependency between agents (e.g. production decisions in one division impact on the production decisions of another).<sup>7</sup> Solutions to the firm's problem then require

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<sup>6</sup> For a more detailed analysis of the nature of the decision process by Leeson and how it caused Baring's downfall see Chapter 1 of Hoch and Kunreuther (2001).

<sup>7</sup> For a comprehensive treatment of principal-agent models see Kreps (1990, Chapter 16). For a discussion of multiperson principal-agent problems, see Kleindorfer et al. (1993, chapter 7). There is also a

both an understanding of the impact of incentives on individual agents as well as the anticipated behavioral responses of these agents to one another. While some of the multi-agent design literature on collective choice (e.g., Groves (1979)) has addressed the issue of externalities across agents, there has been no work undertaken to date on how to deal with the type of interdependent security problems described in this paper.

For the IDS problem there is a need to provide either special economic incentives to key units in the organization to induce tipping behavior or to apply a subsidy or impose a tax on all the agents. For example, if the CMC taxed all divisions a certain amount if they did not adopt cost-effective protective measures, then they would want to invest in these actions if the penalty was high enough (Kunreuther and Heal 2002). More generally, there is a need to develop principal-agent models that examine the efficacy of alternative policy instruments that the principal could apply when there are contamination effects between agents.

### **4.3 Multi-Period and Dynamic Models**

Deciding whether to invest in protection normally involves multi-period considerations since there is an upfront investment cost that needs to be compared with the benefits over the life of the protective measure. A division that invests in a protective measure knows that this action promises to offer benefits for a number of years. Hence it needs to discount these positive returns by an appropriate interest rate and specify the relevant time interval in determining whether or not to incur this investment cost. There may be some uncertainty with respect to both of these parameters.

From the point of view of dynamics, the decision to invest depends on how many others have taken similar actions. How do you get the process of investing in security started? Should one subsidize or provide extra benefits to those willing to be innovators in this regard to encourage others to take similar actions? The nature of the decisions undertaken by divisions and the CMC of the firm will undoubtedly be different in a dynamic environment where learning can take place than in the one-period model developed in this paper.

### **4.4 Examining Alternative Decision Rules**

Individuals and firms often utilize simplified decision rules when determining what courses of actions to follow. One rule that is often followed by managers is a threshold model of choice whereby action is taken only if the chance of some event occurring is above a critical probability level. If the perceived probability is below this level than it is assumed that this event is not worth worrying about.

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rich literature on the design of organizational incentives to account for interdependency problems across divisions. This includes the well-known work of Groves (1979) and Holmstrom (1982), with more recent contributions summarized in Gibbons (1998).

Empirical research has provided evidence that decision-makers use *threshold-like models* in making their decisions. In a laboratory experiment on purchasing insurance, many individuals bid zero for coverage, apparently viewing the probability of a loss as sufficiently small that they were not interested in protecting themselves against it. [McClelland, Schulze and Coursey (1993)] Similarly, many homeowners residing in communities that are potential sites for nuclear waste facilities have a tendency to dismiss the risk as negligible. [Oberholzer-Gee (1998)]. In interview with managers at the Chemco Company after the Bhopal disaster, Bowman and Kunreuther (1988) discovered that the firm had an informal rule that it would only concern itself with the dangers of specific chemicals if the probability of an accident was above a certain threshold level.

Suppose a manager utilizes the following rule for its division: only invest in protection if the probability ( $p$ ) of having a catastrophic accident that causes its division to go bankrupt is greater than some prespecified value. One could estimate what this threshold probability would have to be so that the division's behavior would be consistent with maximizing the expected returns of its employees.

Consider Division 1 of the firm. Let  $n^*$  be the number of other divisions who do **not** invest in protection against catastrophic accidents. One can determine how this threshold probability would be affected as  $n^*$  changes. Define  $p_{n^*}$  to be the probability where Division 1 would be indifferent between investing and not investing in protection if it were maximizing the expected returns of its employees.

Suppose  $n^*=0$  so that all other divisions have invested in protection. Division 1 will be indifferent between investing and not investing in protection if  $p_0L=c$ . Hence  $p_0=c/L$ . If  $n^*=1$  then this is equivalent to the case in a two division firm where Division 2 does not invest in protection. Now the decision rule for Division 1 to be indifferent between investing and not investing in protection is  $p_1(1-q)=c/L$ . Hence  $p_1 > p_0$ . As the value of  $n^*$  increases then one can show that  $p_{n^*}(1-q)^{n^*-1}=c/L$  so that  $p_{n^*} > p_{n^*-1}$ .

This rule implies that as more divisions do **not** invest in protection, the reduction in the probability of BeSafe going bankrupt by Division 1 investing in protection gets smaller. This means that the value of  $p_{n^*}$  that makes it worthwhile for Division 1 to invest in protection must increase for any given  $c/L$  ratio. Hence the larger the value of  $n^*$ , the less likely any division will invest in protection for any given value of  $p$ . The division thus uses the same line of reasoning in specifying a threshold probability as when it is maximizing the expected returns of its employees: investing in protection does less good for the division, the more divisions that have their plants unprotected against a catastrophic accident that could bankrupt the firm.

#### 4.5 Role of Coordinating Mechanisms

Suppose that one was investigating the IDS problem in the context of firms in an industry rather than divisions in a firm. An example would be the airlines where there is concern by each company that an uninspected bag transferred from another airline would contain a bomb. One way to convince the  $n$  airlines that it would be in everyone's best interests to

invest in baggage security would be to utilize some official organization to coordinate these decisions. For example, the International Air Transport Association (IATA), the official airline association, has indicated on its Web site that since Sept. 11<sup>th</sup> they “have intensified hand and checked baggage processing”. IATA could have made the case to all the airlines that they would be better off if each one of them utilized internal baggage checking so that the government would not have had to require this.

An association can play a coordinating role by stipulating that any member has to follow certain rules and regulations including the adoption of security measures and has the right of refusal should they be asked to do business with an agent that is not a member of the association and/or has not subscribed to the ruling. IATA could require all bags to be reviewed carefully and each airline could indicate that it would not accept in-transit bags from airlines that did not adhere to this regulation.

Apparently IATA follows this type of policy in agreements regarding pricing policies. If an airline does *not* belong to IATA and you want to transfer to this airline from an originating IATA airline, the originating airline will not make a reservation for you. Furthermore an IATA airline will not honor a non-IATA airline ticket unless it conforms to the IATA tariff conference.<sup>8</sup>

On a more informal level it might be possible to establish social norms that generate pressure to invest in protection (Sunstein 1996). This is not easy to do since there are normally no visible benefits from the investment until after a disaster occurs. Consider the challenges associated with convincing residents in hazard-prone areas to invest in mitigation measures. If opinion leaders can convince others in their community that these investments will yield expected benefits to them as well as their neighbors in the form of lower losses and higher property values, then a social norm may arise which leads residents to adopt cost-effective loss reduction measures.<sup>9</sup>

#### **4.6 Behavioral Considerations**

The models discussed above all assume that individuals make their decisions by comparing their expected benefits with and without protection to the costs of investing in security. There is a growing literature in behavioral economics that suggests that individuals make choices in ways that differ from this rational model of choice. (Kaheman and Tversky 2000).

With respect to protective measures there is empirical evidence from controlled field studies and laboratory experiments that many individuals are not willing to invest in security for a number of reasons that include myopia, high discount rates and budget constraints. (Kunreuther, Onculer and Slovic 2000). In the models considered above there were also no internal positive effects associated with protective measures. Many individuals invest in security to relieve anxiety and worry about what they perceive might

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<sup>8</sup> See the IATA web site at <http://www.iata.org/membership/steps.asp#10>

<sup>9</sup> See Ostrom (1990), particularly chapter 6 that deals with the conditions under which norms evolve governing the use of common property resources.

happen to them or to others so as to gain peace of mind (Baron, Hershey and Kunreuther 2000).<sup>10</sup>

A more realistic model of interdependent security that incorporated these behavioral factors, relevant constraints and people's misperceptions of the risk may suggest a different set of policy recommendations than those implied by a rational model of choice. For example, if agents were reluctant to invest in protection because they were myopic, then some type of loan may enable them to discern the long-term benefits of the protective measure. A long-term loan would also help relieve budget constraints that may deter some individuals or firms from incurring the upfront costs of the risk-reducing measure.

#### **4.7 Estimating the Risk of an Accident**

The IDS model we have developed assumes that the probability and outcomes of a particular event are well specified. In reality there is considerable ambiguity associated with these data. There is thus a need to examine the impact of ambiguity on decisions on whether or not to invest in protective measures. Furthermore there is a need to collect better data on the risk in order to estimate the chances and consequences of a catastrophic accident.

Currently the Wharton Risk Management and Decision Processes Center is engaging in two types of data collection efforts in this regard with the U.S Environmental Protection Agency. The first of these uses accident history data from the U.S. Chemical industry, and the second is concerned with the performance of management systems designed to improve the environmental, health and safety (EH&S) performance of companies.

Accident history data has been collected on the performance of the U. S. Chemical industry for the period 1995-2000, under Section 112(r) of the Clean Air Act Amendments of 1990. Every chemical facility in the United States was required to provide these data for any listed chemical (140 toxic and flammable chemicals in total) above threshold quantities. Elliott, Kleindorfer and Lowe (2001) indicate how these data can be used to analyze potential relationships between the following factors:

- The Characteristics of the Facility itself, including facility location, size and the type of hazard present (as characterized by the chemicals and process used, the training and management systems in place, and other facility-specific characteristics)
- The nature of regulations in force that are applicable to this Facility and the nature of enforcement activities

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<sup>10</sup> Of course, if these individuals become aware that substantial losses may be imposed on them or their firm from others who are unprotected, then this new knowledge may increase their anxiety by showing that investing in these protective measures has more limited benefits than they had initially assumed it would.

- The level of pressure brought on the Facility to operate safely and to inform the community of the hazards it faces;

These same data can be linked to financial information so one can analyze the association, if any, between the financial characteristics of the parent company of a facility and the frequency or severity of accidents. Similarly, the property damage estimates, and associated indirect costs from these, can be used to assess the consequences of EH&S incidents on overall company performance and provide valuable insights for insurance underwriting for such accidents. Finally, the same data can be used to assess worst-case consequences from such incidents, including those that might arise from site security risks associated with terrorism.<sup>11</sup>

The second data collection project is a study of “near misses” in organizations and the systems that have been put into place to report and analyze these data. Near misses are defined as incidents that, under different circumstances, could have resulted in major accidents. Linking these data on accident precursors to the Accident History database in RMP\*Info, may enable one to identify categories of precursors that give early warnings of the potential for major accidents. Audit tools and other aspects of near-miss management can then focus not just on emergency response but on the range of prevention and mitigation activities before the fact that can help avert major disasters.<sup>12</sup> Even with these data, there will still be considerable uncertainty regarding the estimates of risks associated with these low probability events.

#### **4.8 Evaluating Similarities and Differences Between IDS Problems**

Two common features of IDS problems are the possibility that other agents can contaminate you and your inability to reduce this type of contagion through investing in security. An agent is thus discouraged from adopting protective measures when it knows others have decided not to take this step. Below we list some other problems besides bankruptcy that satisfy these conditions and deserve more detailed analysis.

- Investing in airline security such as baggage checking systems
- Making buildings more secure against attacks
- Investing in sprinkler systems to reduce the chance of a fire in ones apartment
- Making computer systems more secure against terrorist attacks.
- Investing in protective measures for each part of an interconnected infrastructure system so that services can be provided to disaster victims after the next earthquake.

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<sup>11</sup> For recent details on this aspect of the chemical Accident History Database RMP\*Info, see Kleindorfer et al. (2002).

<sup>12</sup> For details on the Wharton Near-Miss Management Project, see Phimister et al. (2001).

In each of these examples there are incentives for individual units or agents not to take protective measures but there are large potential losses to the organization and to society from their failure to do so. Furthermore the losses are sufficiently high that they are non-additive.

IDS problems can be contrasted with other types of protective measures that do **not** have these features. Two that are discussed in more detail in Kunreuther and Heal (2002) are theft protection and vaccination. In the case of theft protection if you install an alarm system that you announce publicly with a sign, the burglar will look for greener pastures to invade.<sup>13</sup> With respect to vaccines if you knew everyone else has been vaccinated, then there would be no point in getting vaccinated since you cannot catch the disease.<sup>14</sup>

#### **4.9 Final Thoughts**

The events of September 11<sup>th</sup> have highlighted the importance of addressing the questions associated with interdependent security. There are enormous challenges in modeling the nature of the interaction between agents that need to be addressed through future theoretical and empirical studies. By developing a richer set of models and testing them through controlled experiments and field studies we will increase our understanding of the way agents behave and their relationship to models of choice such as the one developed in this paper.

We look forward to working with others on analyzing different problem contexts, modifying the assumptions regarding the sharing of information between different individuals and groups as well as understanding the learning process and dynamic aspects of behavior. Based on these analyses there is a need to reexamine the role of the public and private sectors in developing efficient and equitable strategies for providing protection against catastrophic events so as to reduce their likelihood of occurrence and their potential consequences. Our view is that this is not a bankrupt area for future research.

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<sup>13</sup> Ayres and Levitt (1998) have demonstrated the social benefits of protection when individuals invest in unobservable precautionary measures such as the LoJack car retrieval system that criminals cannot detect.

<sup>14</sup> See Hershey et al (1994) for a more detailed discussion of the role that free riding plays in vaccination decisions.

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