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How Does Ambiguity Affect
Insurance Decisions?

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This paper deals with effects of ambiguity on insurance decisions. After citing real-life situations where ambiguity about probability and/or losses would appear to have affected insurance decisions, we outline effects of ambiguity on insurers predicted by the expected utility model and contrast these with predictions implied by descriptive models of how actuaries and underwriters make decisions. In terms of prices, the principal difference between the two sets of predictions is when losses are perfectly correlated and probabilities are ambiguous. We illustrate effects of ambiguity on insurance decisions using data from two surveys, one of actuaries (Hogarth & Kunreuther 1989a;1989b), the other of underwriters. The former deals only with ambiguity concerning probabilities, the latter with ambiguity concerning both probabilities and losses. The main conclusion is that ambiguity matters in

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terms of quoted prices for insurance. Moreover, at a descriptive level it appears that decision makers utilize heuristics that may lead to different prices than implied by standard economic theory. Finally, we emphasize the need to research how processes within insurance firms (including types of interactions between actuaries and underwriters) as well as institutional aspects of insurance markets combine, in the presence of ambiguity, to affect the supply of insurance.

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A-1

How Does Ambiguity Affect Insurance Decisions?

1.Introduction

There is increasing empirical evidence that one reason why the insurance industry has been reluctant to cover a number of risks is the ambiguity associated with either the probability of specific events occurring and/or the magnitude of the potential consequences.

Regarding ambiguity on the probability dimension, political risk provides an example where few companies offer protection against potential losses of industrial firms investing in developing countries with unstable political systems. Insurers have indicated that their principal reason for not providing coverage has been the difficulty in estimating the probabilities associated with losses of different magnitudes.[1]

Providing protection to manufacturers of the pertussis vaccine against possible brain damage caused by the use of the vaccine illustrates a case where there is considerable ambiguity on the loss dimension.[2] In this case the probability of such serious side effects from the vaccine are well-known but the size of court awards from product liability suits against the manufacturer have made the costs of insurance prohibitive to them. In fact, manufacturers decided not to produce the vaccine because of concern with the potential costs of such liability.[3]

For risks where there is considerable ambiguity on both the probability and outcome dimensions the insurance industry has been unwilling to extend coverage very widely. For example, environmental pollution coverage has been considered uninsurable by practically all major insurance firms.[4] Not only is the probability of a claim against the insurer uncertain, but should a suit be filed against the insured party there is no guarantee that the costs to the insurer will be bounded by the stated limits of coverage.[5][6]

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In the case of earthquake coverage the insurance industry is willing to provide coverage against damage to residential homes and to commercial structures but at premiums that greatly exceed expected loss. One reason for this behavior is that it enables the insurance industry to build up reserves for a large quake. However, for residential insurance where losses are not expected to be high, the premium to loss ratio over the first 60 years that such insurance was offered in California (1916-76) averaged 30 to 1.[7] Firms are reluctant to lower their rates and are anxious to develop some type of government involvement to avoid the potentially large losses they feel they would face.[8]

This paper investigates the impact of ambiguity on insurance premiums based on recently completed surveys of both actuaries and underwriters. The data strongly suggest that ambiguity related to both probabilities and losses plays a key role in insurers' decisions on what premiums to charge and what coverage to offer. At a descriptive level this behavior raises questions as to what models of choice each of these groups utilize in making their premium recommendations. At a prescriptive level a relevant question is whether new institutional arrangements are required to replace traditional insurance market mechanisms for providing protection that is currently unavailable.

2. Ambiguity and Insurers Price-Setting Decisions

The premium setting decisions of actuaries and underwriters need to be viewed in the context of an insurance firm's decision on offering coverage in a market setting. To motivate this analysis consider a situation where the insurer is considering selling contingent claims for one time period against a risk where

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there is a nonambiguous probability p that a specific loss L will occur. Assume for ease of exposition that only one loss can occur for any given policy during this time period. If the firm sells m different policies against this risk, then let p_j represent the nonambiguous probability estimate that j losses will occur j=0.....m.

Let us suppose that the insurer determines what premium to set based on an expected profit maximization criterion. For the case where the probability is non-ambiguous and the loss is specified as L let r_1 be the premium where the insurer is indifferent between offering coverage or maintaining the status quo. If A represents the insurer's assets prior to providing coverage, then r_1 is determined by:

$$A = A - \sum_{j=0}^{m} jp_j L + mr_1 \quad (1)$$

In other words $r_1 = \sum_{j=0}^{m} (jp_j)/m$. Since the insurer is risk neutral this means that he sets r_1 equal to the expected loss from a single risk whether the risks of the m policies are independent of each other or correlated in any way.

Now consider the cases where either the probability and/or the loss is ambiguous. We define an ambiguous probability to be one where the experts disagree on the chances of j out of m losses so that some type of aggregation procedure is needed. Specifically, consider the case where k different expert opinions are combined, with p_{ij} representing the probability estimate by expert i that j losses will occur. By according each expert's estimate a weight w_i, with $\sum_{i=1}^{k} w_i = 1$, then a linear weighting rule yields an estimate $p_j = \sum_{i=1}^{k} w_i p_{ij}$. Suppose

the weights are chosen so that $p_j = p_j$ for all values of j=0....m. An ambiguous loss is defined here to be one in which the claim against the insurer can vary between some lower bound L_{min} and an upper bound (normally the policy limit) L_{max} with a mean value given by L.

Under the above definitions it can be easily seen from equation (1) that a risk neutral insurer will charge a premium r_1 whether or not the probability and/or loss is ambiguous. Risk neutrality implies that the variance does not matter in premium determination and hence uncertainty on estimates of probabilities and losses should have no effect on insurers' pricing decisions.

The assumption that insurers are risk neutral with respect to potential losses has been challenged by David Mayers and Clifford Smith[9] in a paper on the corporate demand for insurance and more recently in their study of the demand for reinsurance by property/liability insurance companies.[10] Neil Doherty has made a similar point in a study of insurance contracts written between a corporate insurer and a corporate buyer.[11]

The variance associated with potential losses may be an important feature for an insurer to consider for several reasons. For one thing, the provisions of the corporate tax code implies a convex tax function for low levels of taxable income and a linear function for taxable income above $100,000. Hence, an insurer's tax liability will be lower if the variance of pre-tax income is reduced. As the variance of a loss increases then the chances of insurer insolvency also increases. If there are transaction costs associated with bankruptcy then the expected cost associated with any risk portfolio will be lower as one is more certain of the magnitude of the outcomes.

If insurers prefer to be in a situation with a lower variance, then this

implies that they will charge a higher premium the more volatility there is in the probability distribution of losses. This situation is equivalent to being risk averse. At a more general level Bruce Greenwald and Joseph Stiglitz examine firm behavior when there is asymmetries of information between outside investors who provide capital and inside managers who control its use.[12] They show that if professional managers in firms are rewarded with a share of profits but suffer a large penalty in case the firm suffers bankruptcy, then the firm will behave as if it maximized expected utility u where u is characterized by decreasing absolute risk aversion.

A simple example adapted from Kunreuther[13] contrasts the impact of non-ambiguous and ambiguous probabilities on expected utility for a risk neutral and risk averse firm when L=100 and only two policies are sold by the insurer. Two experts, whose estimates are equally credible (so $w_1=w_2=.5$), are utilized by the insurer. Expert 1 estimates the probability of L on any single policy to be .1 and the other expert estimates this same probability to be .3. This situation can be contrasted with the case where both experts agree that the probability of L on any single policy is .2. Suppose an insurer with assets A arbitrarily set U(A)=0 and utility U(A-100)=-1. If two losses were experienced and the insurer were risk neutral then U(A-200)=-2. A risk averse insurer would set U(A-200)<-2, say U(A-200)=-3.

Figure 1 provides four simple decision trees to illustrate the impact of ambiguity in the probability for independent and perfectly correlated risks. For a risk neutral insurer the expected utility is the same in all four cases since this is equivalent to maximizing expected profits. A risk averse insurer will want to charge a higher premium when losses are correlated and when probabilities are

Non
Ambiguous
Probabilities

Independent Losses

	Utilities	
Loss 1 Loss 2	Risk Neutral	Risk Averse

$p = .2$

$(1 - p) = .8$

$p = .2$

$(1 - p) = .8$

	−2	−3
	−1	−1
	−1	−1
	0	0

$E(U) = -.4 \quad -.44$

Perfectly Correlated Risks

	Utilities	
Loss	Risk Neutral	Risk Averse

$p = .2$

$(1 - p) = .8$

	−2	−3
	0	0

$E(U) = -.4 \quad -.6$

Ambiguous
Probabilities

Expert

	Utilities	
Loss 1 Loss 2	Risk Neutral	Risk Averse

$w_1 = .5$

$w_2 = .5$

$p_1 = .1$

$(1 - p_1) = .9$

$p_2 = .3$

$(1 - p_2) = .7$

$p_1 = .1$

$(1 - p_1) = .9$

$p_2 = .3$

$(1 - p_2) = .7$

$p_2 = .1$

$(1 - p_2) = .3$

$p_1 = .1$

$(1 - p_1) = .9$

Risk Neutral	Risk Averse
−2	−3
−1	−1
−1	−1
0	0
−2	−3
−1	−1
−1	−1
0	0

$E(U) = -.4 \quad -.45$

Expert

	Utilities	
Loss	Risk Neutral	Risk Averse

$w_1 = .5$

$w_2 = .5$

$p_1 = .1$

$(1 - p_1) = .9$

$p_2 = .3$

$(1 - p_2) = .7$

Risk Neutral	Risk Averse
−2	−3
0	0
−2	−3
0	0

$E(U) = -.4 \quad -.6$
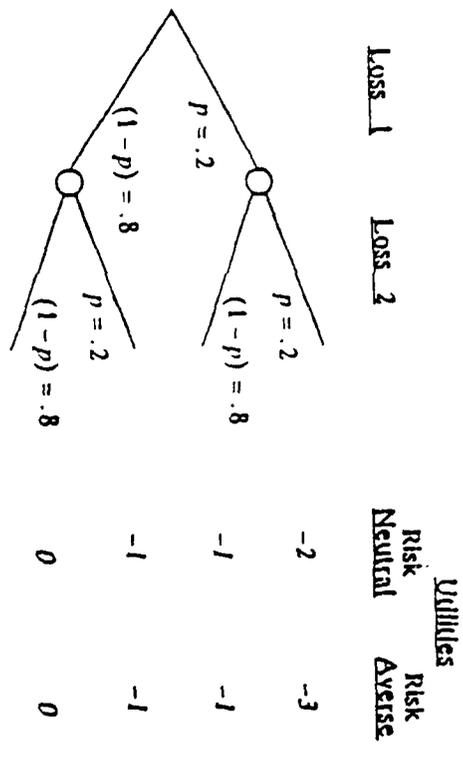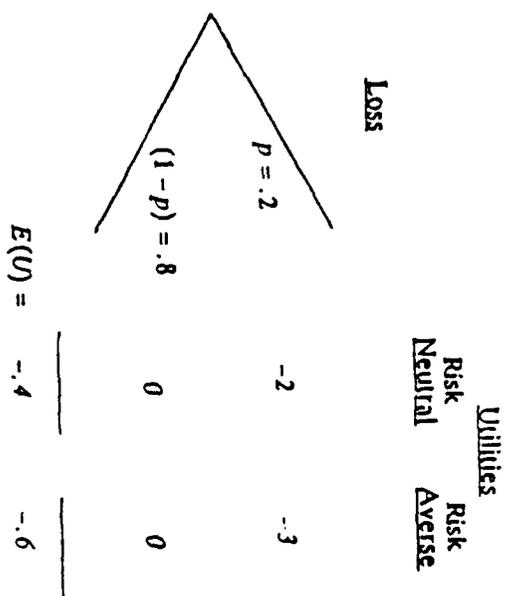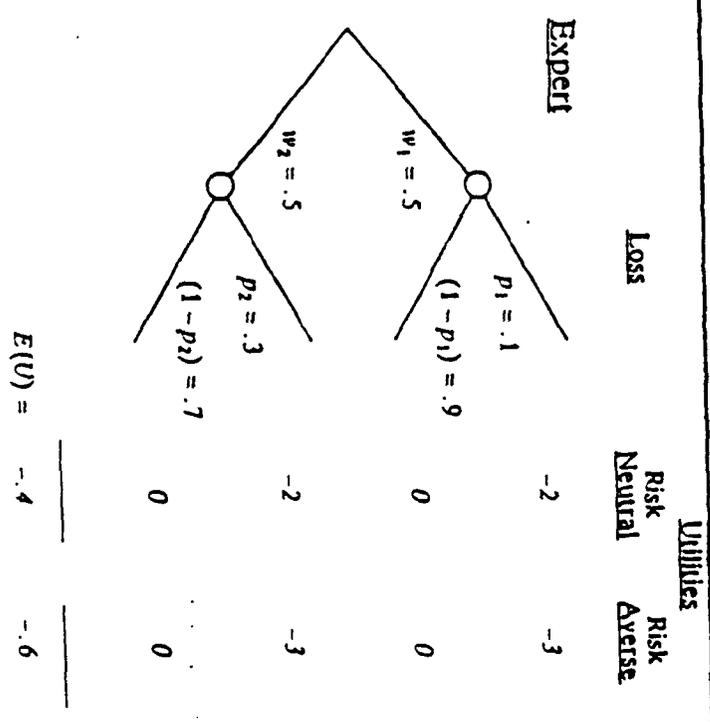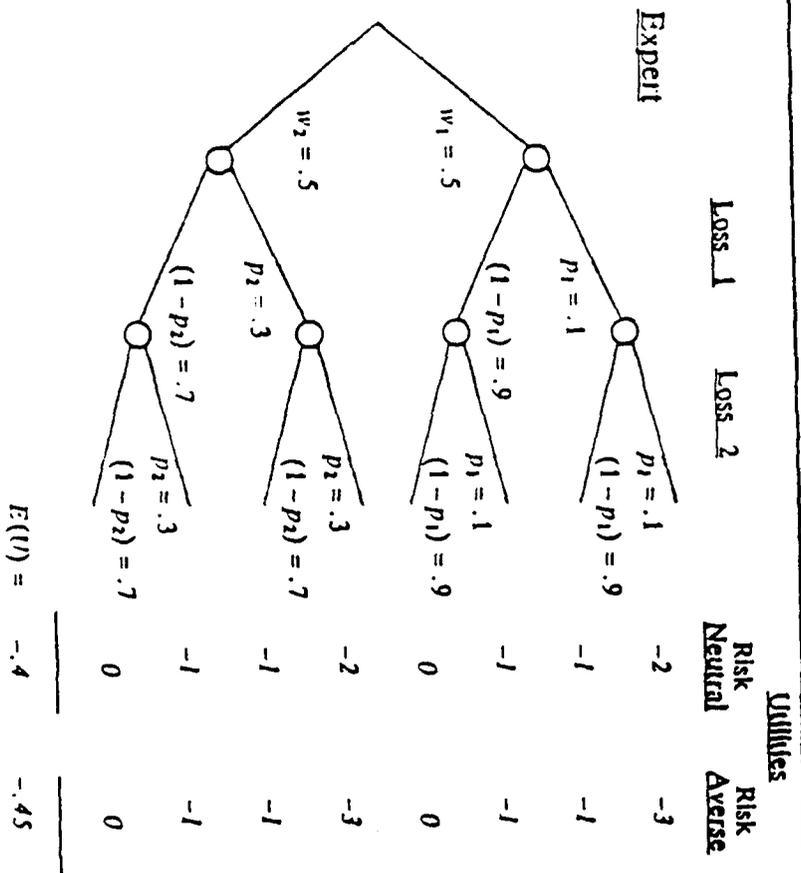
Figure 1: Decision Trees and Expected Utilities for Two Risks Under Different Probability and Loss Conditions

ambiguous.[1]

Ambiguity is thus an important component in determining the market price for coverage if the insurer is risk averse. The variance in either the probability or the actual loss has a negative impact on the insurer's expected utility and thus necessitates a higher premium for the firm to want to market coverage.

3. How Actuaries and Underwriters Determine Premiums

The above discussion implicitly assumed that the insurer was making pricing decisions that satisfied its shareholders who would otherwise invest in other companies. No attention was given to the actual decision-makers in the firm---the actuaries and the underwriters. Both of these groups play critical roles in the premium-setting process and may create additional reasons as to why premiums will be higher as the variance associated with a given risk increases.

How actuaries and underwriters actually behave will be determined in part by how they are evaluated and remunerated. Agency theory arguments have been used to determine optimal compensation packages for corporate decision makers and the nature of such compensation reflects a trade off between risk sharing and efficiency considerations.[14][15] For example, payment by salary may be efficient from a risk bearing viewpoint if shareholders have a comparative advantage over managers in bearing risk. However, a fixed salary does not align rewards to managers and shareholders and the subsequent agency problem ensues. Optimal contracts often require that managers bear some risk and hence require

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[1] This example could be extended to the case where losses are ambiguous. In comparing situations where the expected loss is the same, a risk averse insurer would always charge a higher premium if there was variation in L than if L were constant.

an appropriate risk premium. This risk premium is with the firm (i.e., owner).
These considerations imply that if risk to the insurer can be reduced, there is a
gain which can be divided between the various corporate shareholders.

We will assume that actuaries and underwriters in different insurance
companies are paid the same salary regardless of the risks that they insure
against. In this situation the only way for these employees to reduce the chances
of insolvency of the firm on high variance risks is to suggest charging a higher
premium than if the probability distribution of losses were more stable.

In practice actuaries and underwriters utilize heuristics which explicitly
address these concerns in recommending premiums for coverage against specific
risks. Actuaries first determine a premium based on expected value under the
assumption that the probability and loss is known. They then increase this value
to reflect the amount of perceived ambiguity in either the probability and/or loss.[2]

For example, one formula utilized for determining a premium r is

$$r = (1 + \lambda) \mu$$

where μ = expected value (i.e. p x L) and λ ($\lambda > 0$) is a factor reflecting ambiguity.
The value of λ varies depending upon the situation but is considered by actuaries
as a global security loading independent of any adjustment to cover
administrative costs.[17]

Other models of behavior explicitly focus on the impact of constraints on
individual behavior under uncertainty. Almost forty years ago Bernard Roy[18]
developed a model of choice in which firms were guided in their actions by
keeping the probability of a large loss (which might cause bankruptcy) to be as low

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2 This procedure is similar in spirit to the model proposed by Hillel Einhorn
and Robin Hogarth[16] on how people assess ambiguous probabilities. Their theory
is based on the principle that people first anchor on an initial estimate of the
probability and adjust this anchor by imagining other values that the probability can
take.

as possible. In other words, firms were first concerned with their safety and then with profit maximization. Hence the term "safety-first" behavior was used to describe their actions.

James Stone[19][20] developed a model of underwriting behavior which incorporated some of the ideas of safety first behavior. Let X be a random variable representing the total loss from the insurer's current portfolio of risks. If the underwriter is considering insuring an additional risk where the firm expects to sell m policies each of which can create a loss L then the underwriter will recommend a premium r so that

$$\sum_{j=j^*}^{m} \{\text{Probability } [(X + jL) > (A + mr)]\} < p^* \quad (2)$$

where j^* is the minimum number of losses where $X + j^*L > A + mr$ and p^* is a preassigned probability that reflects safety first considerations. The expression in the brackets represents those events where the total loss is greater than the assets of the firm, thus leading to insolvency. As the variance associated with the loss distribution increases then there is a greater chance of insolvency and hence a need to raise the premium r to satisfy the safety-first constraint given by (2). Stone[19][20] provides illustrative examples as to how variance in losses leads the underwriter to set higher premiums than would have been predicted if he were behaving as if he maximized expected profit for the firm.

3. Empirical Evidence on Insurers Decision Processes

To determine the impact of ambiguity on insurer behavior one can construct a matrix such as Table 1. It specifies the four different premiums based on whether probability and/or loss are ambiguous or precise.

	Precise	Ambiguous
Precise	r_1	r_2
Ambiguous	r_3	r_4

Loss

Table 1 Different Levels of Knowledge for Loss and Probabilities

To better understand the premium-setting behavior of insurers when the risks are ambiguous or nonambiguous, questionnaires were developed with different scenarios. One mail survey was conducted with professional actuaries and another with underwriters, each one tailored to the types of decisions that these groups make. In the case of the actuaries, the survey compared the pure premiums for situations where the loss was known and the probabilities were either precise (r_1) or ambiguous (r_2). Losses were either independent of each other or perfectly correlated.[See [21][22] for more detail] For the underwriters another set of scenarios were constructed that examined all four cells in Table 1 for a single risk in different contexts.

Actuary Survey In the case of the professional actuaries, data were obtained from a mail survey of members of the Casualty Actuarial Society residing in North America. Of this population, 489 of 1165 persons (i.e. 42%) provided usable responses, all anonymously.

Scenarios were designed around five different situations: (1) Defective

product: The owner of a small business with net assets of $110,000 seeks to insure against a $100,000 loss which could result from claims against a defective product; (2) Brown River: A small businessman faces a potential loss of $100,000 from the possible flooding of the Brown River; (3) Palcam: a firm wants to set the price of a warranty for a possible defect in a new personal computer called Palcam-X which would cost $400 to repair; (4) Computeez: A manufacturing company wants to determine the price of a warranty to cover the $100 cost of repairing a component of a personal computer; (5) Health: A major health insurance company wants to determine what additional premium to charge for complications arising from a certain surgical procedure.

All these scenarios specified precise loss estimates but defined the probabilities to be either precise or ambiguous. Hence, actuaries were only asked to indicate the premiums r_1, or r_2 from Table 1. In the scenarios with precise probabilities the actuaries were given a specific probability level (ranging from .001 to .90) and were told that they could "feel confident" about the estimate either because they had sufficient data from past experience (e.g. the defective product scenario) or the experts agreed on the chances of a loss (e.g. Computeez). For the case of an ambiguous probability the actuaries were given the same probability estimate as in the nonambiguous case but were told that they experienced considerable uncertainty concerning the estimate (e.g. defective product scenario) or there was considerable disagreement among the experts (e.g. Computeez). With the exception of the Brown River scenario no range of probability estimates were given when the experts disagreed.[3]

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[3] In the Brown River scenario the non-ambiguous case was presented as a flood with probability .01. In the ambiguous scenario actuaries were told that hydrologists were "sufficiently uncertain about this annual probability that it could range anywhere from zero to 1 in 50 depending on climatic conditions."

The ratio of coverage per dollar premium (denoted by C) provides an indication of the impact that ambiguity has on the prices charged by insurers.[4] Table 2 contrasts the median values of C when actuaries were asked to specify the minimum pure premium they would charge when probabilities were either non-ambiguous (precise) [NA (p)] or ambiguous [A(p)] for the defective product and Computeez scenarios specified above.[5] The figures are revealing. The first row in each scenario, labeled 1/p, specifies the value of C if an actuarially fair premium were charged for a risk that has a probability p of occurring. Values of C less

than 1/p imply that the insurer is charging a premium in excess of expected loss. The next two rows present the median values of C for the non-ambiguous and am-biguous probabilities respectively. In all cases the value of C is decreasing when the probability of a loss changes from precise to ambiguous. The differences are particularly striking when the probabilities are relatively low (i.e., p = .01 and p = .001).

The Computeez scenario is of particular interest as the actuaries were asked to specify premiums when losses were independent or perfectly correlated. If actuaries are setting premiums so as to ma.imize expected profits of the firm, then the premiums should be unaffected by either ambiguous probabilities or correlated losses. If, on the other hand, the actuaries are risk averse, then expected utility theory implies that premiums should be higher for ambiguous probabilities than for nonambiguous probabilities if losses are independent. For

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[4] We are indebted to David Hildebrand for suggesting the use of this measure.

[5] For the defective product scenario each actuary responded to both the am-biguous and nonambiguous version. For the computeez scenario each actuary responded to either a nonambiguous or ambiguous version. The versions were the first and last questions for several the actuaries were asked to answer. Each question appeared on a different page of the questionnaire and the order of the ambiguous and nonambiguous and nonambiguous versions were randomized across subjects.

Table 2

Actuaries Estimates of Coverage per Dollar Premium (C) for Different Scenarios (Median Values)
For Nonambiguous Probabilities [NA(p)] and Ambiguous Probabilities [A(p)]

Defective Product Scenarios *

Loss = $ 100,000

	p = 0.01	p = 0.35	p = 0.65	p = 0.90
1/p	100	2.86	1.54	1.11
NA(p)	65	2.34	1.43	1.11
A(p)	20	2.00	1.25	1.05

Computeez Scenarios**

100, 000 units Insured
L = $100

	Independent Risks			Perfectly Correlated		
	p = 0.001	p = 0.01	p = 0.10	p = 0.001	p = 0.01	p = 0.10
1/p	1000	100	10	1000	100	10
NA(p)	909	95	10	1000	82	8.3
A(p)	200	50	8.3	100	9	4.0

* The number of actuaries responding to these scenarios ranged from 9 to 15

** The number of actuaries responding to these scenarios ranged from 14 to 22

perfectly correlated risks, the premiums should remain the same whether the actuary is risk neutral or risk averse.

The values of C presented in Table 2 indicate that the actuaries specified considerably higher premiums for perfectly correlated risks than independent risks when 100,000 units are insured. For ambiguous probabilities they reacted by increasing the premium (i.e., reducing C) particularly for the perfectly correlated case. Thus when p=.01, the actuarially fair value is C=100. When losses are perfectly correlated and the actuary faces an ambiguous probability, the median value is C=9. The probability would have to be p = .111 for this median premium to be actuarially fair.

These data suggest that actuaries are extremely risk averse when they face a potentially large loss and are uncertain about the chances of it occurring. They may feel that they will be held responsible should such an event occur. By charging a premium somewhat in excess of expected loss they can provide some type of justification for their actions to others, in this case the underwriters.[23]

A focus group with four actuaries from a large insurance firm in the Philadelphia area provided considerable insight into the basis for the question-naire responses. There was general agreement in the group that ambiguity on probabilities greatly increases the perceived risk, particularly if there is a large exposure (as in the perfect correlation Computeez case). One actuary in response to this scenario, indicated that if the risks were perfectly correlated and the probability was ambiguous he would either refuse to provide coverage or demand a premium that was "near 100 cents to the dollar."

Underwriter Survey   The questionnaire on the underwriter premium-setting process was constructed so that data for all four cases in Table 1 could be collec-

ted. After conducting informal group discussions and personal interviews with underwriters in the Philadelphia area, we mailed packets of questionnaires to the chief property and casualty underwriters in 190 insurance companies throughout the United State, asking each to distribute them to underwriters who reported to them in their firms. We received 222 completed questionnaires from 47 insurance companies.[6]

Each underwriter was asked to respond to four different neutral scenarios reflecting the conditions on probability and loss depicted in Table 1.[7] For example, in order to determine r_1 in Table 1 the underwriter was told that he faced a given risk where, if a loss occurred, it would equal L dollars and that all the experts agree that the annual probability of the loss was p. Ambiguous probabilities were defined as "wide disagreement and a high degree of uncertainty among the experts." The precise loss was specified at L=$1 million or L=$10 million. Precise values of the probability were set at p=.01 or p=.005. For the case of a vague loss, estimates ranged from negligible to either $2 million or to $20 million depending on whether the best estimate was $1 million or $10 million.

In order to determine whether specific risk contexts influenced the premium-setting process, each underwriter was given either a set of four scenarios related to insuring a commercial building against earthquake damage of $ L million or providing coverage against pollution damage of $ L million from

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7 The scenarios were labeled neutral in that there was no context associated with the particular risk.

the leakage of an underground storage tank.[8]

Figure 2 provides a summary of the values of C for three sets of scenarios where p=.01 and L=$ 1 million. The actuarially fair value is C=$100. As with the actuaries, the underwriters charge higher premiums when either p and/or L is ambiguous. Even for the case where precise estimates of p and L are given the values of C are relatively low ranging from 63 in the neutral scenario to 51 in the earthquake scenario. For the case where both p and L are ambiguous then the C ratio is very low for all three types of scenarios. Although the data depicted in Figure 2 did not reveal a large difference between the three types of scenarios, it was generally true that a potential hazardous waste loss induced underwriters to charge a higher premium than for the other two scenarios. Hence, C was the lowest for this situation. In general, ambiguity of probability had more of an impact in raising premiums than ambiguity on the loss.

4. Implications for Market Behavior

The empirical data on actuary and underwriter behavior suggest that ambiguity on either probability and/or losses will lead to higher premiums than if the risk was precisely specified. In certain cases, such as political risk and environmental pollution there is a reluctance by most insurers to offer any coverage on the market. For other risks such as earthquake, private insurers are looking for ways to bring the federal government in as partners.

The principal reason why actuaries and underwriters want to charge higher premiums when there is ambiguity is because all potential policyholders are affected in the same way by the uncertainty regarding probability and/or

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[8] A Latin Square design was constructed for determining what values of p and L each underwriter was given for the different sets of four scenarios.

Figure 2
## Mean Coverage Per Dollar
p = .01, L = $1 million

Earthquake Scenario
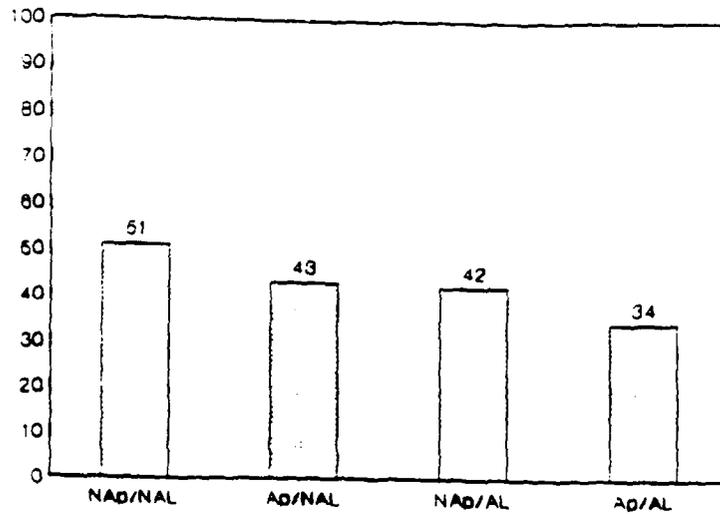
Hazardous Waste Scenario
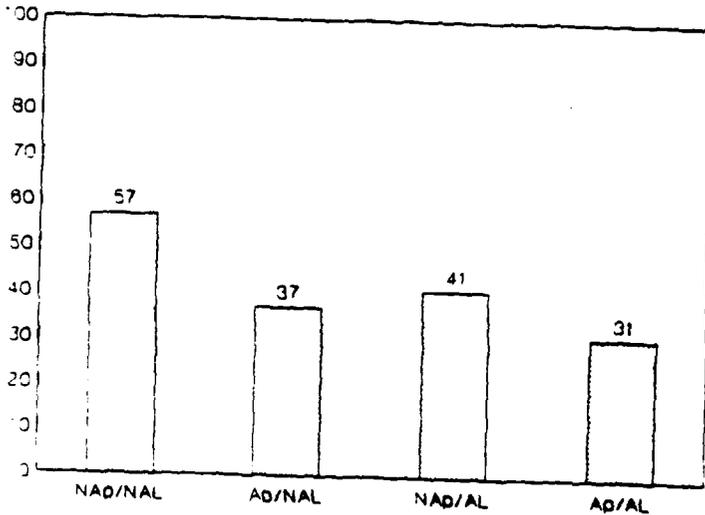
Neutral Scenario
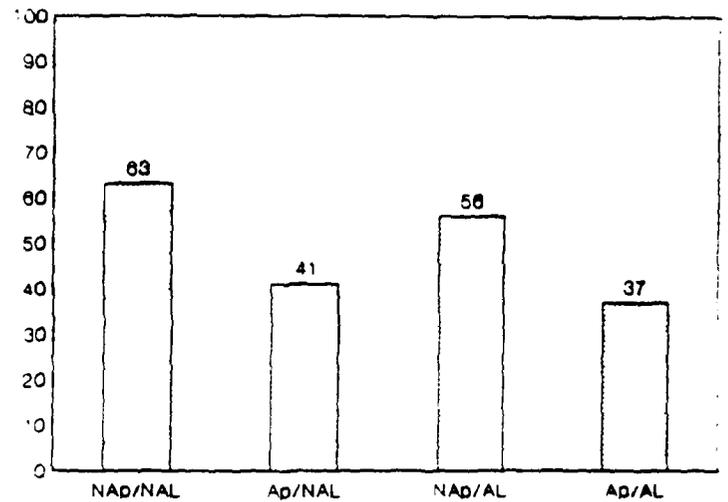
Legend

		LOSS	
		Non-Ambiguous	Ambiguous
PROBABILITY	Non-Ambiguous	NAp/NAL	NAp/AL
	Ambiguous	Ap/NAL	Ap/AL

losses. If there is a lack of understanding of the mechanism causing a loss, then this uncertainty will affect all of the risks. Similarly if one is uncertain as to what type of liability ruling will be invoked should a claim be made on one policy, then this uncertainty will affect all policies.

Risk assessment techniques can shed light on the perceived probability, and clearer specification of liability rules can reduce the uncertainty of losses. However, there is little indication that there will be rapid movement in these directions in the next few years. Hence, one may want to turn to alternative institutional arrangements rather than standard insurance contracts as a way of resurrecting the market.

Mutual Insurance Mutual insurance arrangements should be an attractive way of providing protection to individuals or industrial firms facing an ambiguous risk. Each member of the mutual company contributes a sum of money entitling them to insurance protection and at the end of the year dividends are paid out if there is a surplus. The parameters associated with the risk do not have to be precisely estimated and claims experience over the years can help specify the loss distribution. Neil Doherty and Georges Dionne[24] have shown that mutual-like insurance is preferable to standard coverage when losses are correlated.

Risk retention groups have now emerged as a viable type of mutual arrangement whereby industrial firms contribute their own capital to a pool of companies as a way of obtaining insurance protection. Risk assessments are needed to delineate differences between firms and to determine how contributions to the group should vary. At the same time there needs to be appropriate monitoring and control procedures at regular intervals to assure that the firms are meeting prescribed standards and to avoid moral hazard problems.

Although in theory the concept of risk retention groups appear to be a viable institution, few have formed over the past few years. One difficulty associated with creating these groups is that many potential member feel that they are better than average and will contribute more in capital contributions than they will receive in return. Hence the importance of risk assessment procedures and enforcement of standards to allay these concerns. Another reason is the feeling on the part of firms who already are part of a pool that they would prefer not to have competitors join the group since those insured feel they have a comparative advantage over uninsured rivals. The insurer who forms this pool needs to clarify at the outset that their intention is to expand it to many companies and that there are large advantages to the size and stability of the pool through diversifying.

Government Reinsurance One way to reduce the concern by insurers with ambiguity on the loss side is to have some partial government involvement for handling unusually large unanticipated losses if the reinsurance industry is unwilling to do so. For example, if there is a severe earthquake which damages a large number of homes then it may be necessary for the government to cover a portion of the catastrophic losses.

There is precedence for this type of arrangement for risks where there is considerable ambiguity regarding losses. The Price Anderson Act of 1975 formed two insurance pools which provided $60 million of liability coverage to protect nuclear power plant operators with the federal government providing up to $500 million of additional indemnity due to the limited experience with nuclear power at the time and to encourage the construction of nuclear power plants. Today the government has phased out the program and each nuclear power plant's liability

has been increased so that should an accident occur the total amount of financial protection would exceed \$7.2 billion.[25]

The National Flood Insurance Program was passed in 1968 because private companies refused to market coverage for water damage partly due to this ambiguity associated with potentially catastrophic losses. One of its principal features was a government reinsurance program. The insurance industry has proposed a similar arrangement for earthquake protection. Current rates would be lowered from their present level on all structures in exchange for government reinsurance protection in case of a catastrophic quake where the insured damage exceeded a certain level.[8]

Conclusions

A principal conclusion emerging from surveys of actuaries and underwriters is that they will add an "ambiguity premium" in pricing a given risk whenever there is uncertainty regarding either the probability and/or losses. At a descriptive level both decision makers are utilizing heuristics that may lead to different predictions from standard economic theory. In particular when presented with a single risk or a perfectly correlated set of risks, standard models of choice predict that the premiums will be the same whether the probability is precise or ambiguous. In fact, they are not.

These findings raise a number of questions regarding the decision-making process in an insurance firm. For example, it is important to understand more fully the types of constraints affecting underwriters and actuaries in their determination of premiums and how the two groups interact with each other in both formal and informal ways. What specific quantitative and qualitative factors are important to actuaries and underwriters when confronted with uncertain

risks? What role does availability of reinsurance, surplus and capacity of the firm play in determining recommended premiums and whether coverage should be offered by the insurer? How important is the portfolio of other insured risks in the actuary and underwriter's process?

By understanding more fully the answers to these questions one can determine whether certain prescriptive measures are likely to impact on the decision-making process in insurance firms. What is the value to insurers of additional data designed to reduce the ambiguity associated with the risk? What efforts should be undertaken by the insurer to increase the amount of its reinsurance given the nature of its portfolio of risks? Finally what are the potential roles of new institutional forms such as mutuals and public-private sector programs in resurrecting markets for coverage? It is clear that ambiguity matters to insurers and for this reason alone we need both to understand it better and to develop more creative approaches for dealing with it.

References

[1] Kunreuther, Howard C. and Kleindorfer,Paul R. (1983), "Insuring Against Country Risks: Descriptive and Prescriptive Aspects." In R. Herring (ed.), Managing International Risk. Cambridge, UK: Cambridge University Press.

[2] Hinman, Alan and Kaplan, J. (1984), "Pertussis and Pertussis Vaccine," Journal of American Medical Association 251: 3109-3113, June 15.

[3] Huber, Peter (1983) Liability: The Legal Revolution and Its Consequences New York: Basic Books

[4] Carter, Robert (1990) Liability for Accidental Pollution : Obstacles to the supply of Insurance, Landon: The Chartered Insurance Institute.

[5] Abraham, Kenneth, (1988) "Environmental Liability and the Limits of Insurance, Columbia Law review 88, 942-988.

[6] Katzman, Martin, (1983), "Chemical Catastrophes," (Richard D. Irwin. Homewood,Illinois).

[7] Atkisson, Arthur and Petak, William (1981). "Earthquake Insurance: A PublicPolicy Analysis." Report prepared for the Federal Insurance Administration, Federal Emergency Management Agency, Washington, DC 20472.

[8] National Committee of Property Insurance (1989), "Catastrophic Earthquakes: The Need to Insure Against Economic Disaster," (Mimeo), Boston, MA: The Earthquake Project.

[9] Mayers, David and Smith, Clifford (1983) " On the Corporate Demand for Insurance" Journal of Business 55:281-296.

[10] Mayers, David and Smith, Clifford (1989) " On the Corporate Demand for Insurance: Evidence from the Reinsurance Market", Proceedings of the International Insurance Society.

[11] Doherty, Neil (1989) " The Design of Insurance Contracts when Liability Rules are Unstable" (Unpublished Paper, Wharton School, University of Pennsylvania).

[12] Greenwald, Bruce and Stiglitz, Joseph (1990) "Asymmetric Information and the New Theory of the Firm: Financial Constraints and Risk Behavior" American Economic Review: Papers and Proceedings 80:160-165.

[13] Kunreuther, Howard (1989) "The Role of Actuaries and Underwriters in Insuring   Ambiguous Risks" Risk Analysis 9:319-328

[14] Lambert, Richard and Larcker, David (1985) "Executive Compensation, Corporate Decision-making and Shareholder Wealth: A Review of the

Evidence' Midland Corporate Finance Journal 2:6-22.

[15] Mayer, David and Smith Clifford (1989) "Executive Compenstaion in the Life Insurance Industry" Working Paper, University of Rochester.

[16] Einhorn, Hillel J. and Hogarth Robin M. (1985), "Ambiguity and Uncertainty in Probabilistic Inference," Psychological Review 92, 433-461.

[17] Lemaire, Jean. (1986), Theorie Mathematique des Assurances (Presses Universitaires de   Bruxelles, Belgium).

[18] Roy, Bernard (1952) "Safety-First and the Holding of Assets" Econometrica, 20:431-49.

[19] Stone, J., (1973a) "A Theory of Capacity and the Insurance of Catastrophic Risks,"Journal of Risk and Insurance, 40, 231-243.

[20] Stone, J., (1973b) "A Theory of Capacity and the Insurance of Catastrophic Risks,"Journal of Risk and Insurance 40, 339-355.

[21] Hogarth, Robin and Kunreuther, Howard (1989a) "Risk, Ambiguity and Insurance"   Journal of Risk and Uncertainty 2:5-36

[22] Hogarth, Robin and Kunreuther, Howard (1989b) "Pricing Insurance and Warranties:Ambiguity and Correlated Risks" Wharton Center for Risk and Decision Processes Working Paper.

[23] Tetlock, Phillip (1985) " Accountability: The Neglected Social Context of Judgments and Choice" Research in Organizational Behavior, vol 7. (JAI Press, Greenwich, Conn).

[24] Doherty, Neil and Dionne, Georges (1989) "Risk Pooling, Contract Structure and Organizational Form of Insurance Firms: Working Paper, Wharton School, University of Pennsylvania

[25] American Nuclear Insurers)1989 "Nuclear Liability Insurance: Protection for the Public," Report #2, March, (mimeo).

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