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Key words: insurance, experimental economics, prospect theory

Abstract

This article extends the large amount of research on double-oral auction markets to hazards that produce only losses. We report results from a series of experiments in which subjects endowed with low-probability losses can pay a premium for insurance protection. Insurers specify the price at which they are willing to assume the risk of a loss. Insurance prices approach expected value for a large range of probabilities and loss amounts. Subjects seem to realize losses are statistically independent. Prices are not affected by ambiguity about the probability of loss.

In this article, we report experiments on markets for insurance against potential losses. Insurance markets are often considered the paradigmatic example of markets with uncertainty. The traditional theory is that trade in insurance occurs because well-informed individuals are more risk-averse toward losses than are well-diversified and knowledgeable insurance firms (Arrow, 1974). Some examples suggest that insurance markets might not exist when they should because people do not maximize utility or understand probabilities. For instance, Eisner and Strotz (1961) found that flight insurance was popular even though it was overpriced relative to equivalent life insurance. (Mortgage insurance, which pays off a house mortgage when a household head dies, appears to be overpriced too.) Flood insurance is *un*popular even though it is heavily subsidized by the government (Kunreuther et al., 1978).

However, these examples are not conclusive evidence of market irrationality, because apparent deviations from utility maximization and rational probability judgment might be explained by natural complications like transaction and search costs, regulation, and information asymmetries. To see whether insurance markets work well, holding aside the natural complications, we created simple experimental markets.

Our experiments serve three purposes. First, we extend the large amount of research on double-oral auction markets for assets which yield gains (see Smith's 1982 review) to hazards that yield only losses. Second, our experiments contrast expected utility theory with nonexpected utility theories such as prospect theory (Kahneman and Tversky, 1979), a contrast explored in McClelland, Schulze, and Coursey (1986). Third, we test whether trading in insurance is affected by ambiguity in the probability of losses (e.g., Ellsberg, 1961).

The article is structured as follows. In the next section we derive predictions of market equilibrium in our double-oral auction experiments under two competing theories of behavior—expected utility and prospect theory. Sections 2 and 3 present the experimental design and the results when the probabilities of a loss are known with certainty. The impact of probability ambiguity on market equilibrium is examined in sections 4 and 5. Section 6 presents conclusions and discusses future research.

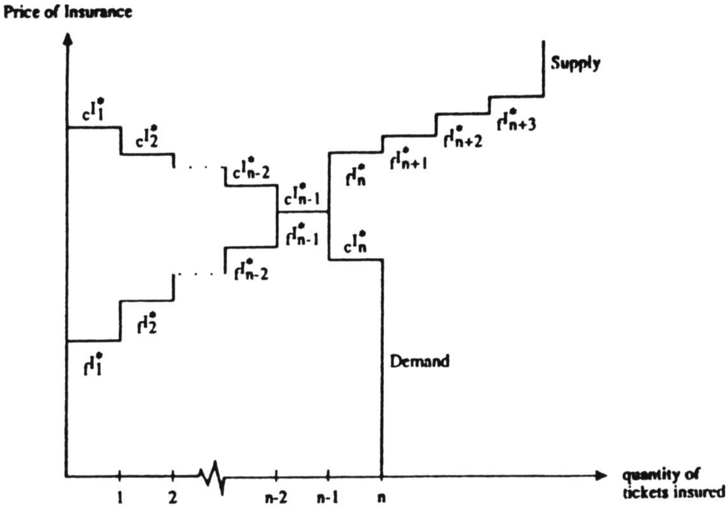
1. Competing theories of market equilibrium

1.1. Supply and demand

To derive predictions about market equilibrium, we assume that each of N consumers is endowed with one hazard (called a *ticket* in our experiments, for reasons discussed below). Each consumer has a reservation price P_c^* at which he or she will buy insurance (full reimbursement for a loss), based on his or her utility function and subjective probability. (We consider two competing theories about these utilities and probabilities—expected utility theory and prospect theory—in more detail below.) We rank these reservation prices from lowest (${}_1P_c$) to highest (${}_NP_c$). Consumers are assumed to be price-takers.[1] Since each consumer is endowed with only one ticket, the market demand curve for insurance is the simple step-function shown in figure 1.

Note that we have not completely determined demand because we have not controlled subjects' utility functions (cf. Roth, 1983; Berg et al., 1986). Instead, we will state different hypotheses about subjects' (uncontrolled) utility functions and test these hypotheses jointly with the hypothesis of competitive equilibrium. Cox, Smith and Walker (1985) and Smith, Suchanek, and Williams (1988) used a similar strategy successfully.

A supply curve can be constructed in the same manner as the demand curve. Assume there are K firms, which can insure as many tickets as they wish, by "purchasing" a ticket from consumers at negative prices. (Individual agents will function as firms in the experiments.)[2] Assume each firm has a utility function which determines a series of reservation prices, P_f^* at which they are willing to sell insurance. Firms can purchase as many tickets as they want, so there will be at least M reservation prices with $M \geqslant K$. If we rank-order these reservation prices



Note: The ${}_cl_i^*$'s are certainty-equivalents for n consumers, ordered so that ${}_cl_1^* > {}_cl_2^* > \dots > {}_cl_n^*$.
The ${}_fl_i^*$'s are certainty-equivalents for each ticket insured by a firm, ordered so that ${}_fl_1^* < {}_fl_2^* < {}_fl_3^* < \dots$

Fig. 1. Competitive equilibrium in the insurance market experiments.

from lowest (${}_1P_f$) to highest (${}_MP_f$) and assume again that firms are price-takers, a step-function supply curve results. Figure 1 shows a portion of the supply curve (which extends well beyond the demand curve, since firms can insure more tickets than consumers own.)

In a competitive equilibrium, the price of insurance will be some P^* (and the quantity of tickets insured will be a corresponding Q^*) that sets ${}_iP_c^* - {}_iP_f^*$ for some i. Figure 1 shows competitive equilibrium with $i - N$, for instance.

There are three important qualifications to this simple model of market equilibrium. First, subjects in market experiments often act as if there are implicit transaction costs that make traders with small amounts of surplus (e.g., a nickel) not worth executing, thus driving a wedge between consumers and firms and reducing the number of equilibrium trades.

Second, the model of competitive equilibrium above is Walrasian, but the experimental markets are organized as double-oral auctions which are not Walrasian (with only 3 to 9 subjects on each side). However, theoretical models of the double-oral auction as a dynamic game with incomplete inforamtion suggest it does converge to Walrasian competitive equilibrium (Friedman, 1984; Wilson, 1985; cf. Easley and Ledyard, 1986). Hundreds of experiments with relatively few buyers and sellers establish this convergence empirically as well (e.g., Smith, 1982).

Third, since consumers and firms are in the insurance market repeatedly, the risk of each ticket need not be considered separately. Indeed, if consumers could exchange a single ticket for $1/n$th of a portfolio of n tickets, their risks would be diversified (completely so, as n gets large) and the price of insurance would necessarily approach the expected value (e.g., Samuelson, 1967).[3] However, consumers cannot buy fractions of portfolios in our experiments. Portfolio risk increases as the number of tickets increases (though not linearly), so a marginal ticket does have *some* risk in the consumers' portfolio. When we make predictions by assuming risk aversion (or risk preference) for a single ticket, the *direction* of those predictions is still correct even if many tickets are traded.

In the simple supply–demand model of figure 1, the equilibrium price and quantity of insurance depends upon assumptions about subjective probabilities and utilities of subjects. We now specify two competing theories, expected utility theory and prospect theory (Kahneman and Tversky, 1979).

1.2. Expected utility theory predictions

Assume that the subjective probability of loss is the same as the objective probability, denoted r, and denote the ticket loss by L. If a consumer's endowment of wealth is W_c, then by not insuring a consumer has an expected utility EU(uninsured) $= rU(W_c - L) + (1 - r)U(W_c)$. By paying a premium P_c, the consumer has EU(insured) $= U(W_c - P_c)$. The consumer's reservation price P_c^* is the value of P_c that makes EU(insured) $= EU$(uninsured). That is, P_c^* is the implicit solution to

$$U(W_c - P_c^*) = rU(W_c - L) + (1 - r)U(W_c). \qquad (1)$$

If a consumer is risk-neutral, then $P_c^* = rL$; a risk-averse consumer has $P_c^* > rL$; and a risk-seeking consumer has $P_c^* < rL$.

Firms with wealth W_f earn $U(W_f)$ by not selling insurance. They earn $rU(W_f - L + P_f) + (1 - r)U(W_f + P_f)$ by selling a single policy at a premium of P_f. Their reservation price P_f^* for determining whether to sell one policy will be to set these two expected utilities equal, implicitly solving

$$U(W_f) = rU(W_f - L + P_f^*) + (1 - r)U(W_f + P_f^*). \qquad (2)$$

As with consumers, firms' reservation prices will be above (below, equal to) the expected value rL if firms are risk-averse (risk-seeking, risk-neutral).[4]

Since there are no productive differences to generate trading, gains from exchange—the gap between the demand and supply curves in figure 1—result only if some of the consumers' reservation prices, P_c^*, are larger than the reservation prices P_f^* for some firms. This will be the case if subjects' risk tastes differ and some consumers are more risk-averse than some firms. Even if subjects have identical risk tastes, trading can occur if their degree of risk aversion is declining with wealth (or if risk-seeking is increasing with wealth), because firms are endowed with more wealth than consumers (i.e., $W_f > W_c$). We state these hypotheses formally (see table 1).

Table 1. Predictions of competing theories

		Predictions about price (P) effect of ambiguity on P				Predictions about quantity (Q) effect of ambiguity on Q		
Hypothesis	Price (P)	Consumer	Firm	Both sides	Quantity (Q)	Consumer	Firm	Both sides
EU								
Decreasing risk aversion	$P > \mathrm{EV}$	None	P greater	P greater	$Q > 0$	None	Q smaller	Q smaller
Increasing risk aversion	$P < \mathrm{EV}$	None	P lower	P lower	$Q > 0$	None	Q greater	Q greater
PT								
Wealth frame	Unknown	P smaller	P smaller	P smaller	$Q > 0$	Q smaller	Q greater	?
Income frame	No trade	None	P smaller	None	$Q = 0$	None	Q greater	None
Segal ambiguity	$P > \mathrm{EV}$	P greater	P greater	P greater	$Q > 0$	Q greater	Q smaller	?

HYPOTHESIS EU1: If subjects are decreasingly risk-averse, trades will take place at prices higher than expected value.
HYPOTHESIS EU2: If subjects are increasingly risk-seeking, trades will take place at prices lower than expected value.

1.3. Prospect theory (PT) predictions

As an alternative to EU, we consider what prospect theory (PT) (Kahneman and Tversky, 1979) predicts about behavior in our insurance markets. In prospect theory, outcomes are evaluated by a value function $v(x)$, where x is the outcome relative to a reference point (or frame). The values of outcomes are then weighted by a function of their probability, $\pi(p)$.

Empirical evidence suggests choices can depend on which of two logically identical frames is used. We distinguish two frames, called the *wealth* and *income* frames. Prospect theory makes predictions about prices and trading volume under each of these two frames (see appendix A for details).

Under the wealth frame, firms and consumers consider all possible gains and losses as changes in the total amount of money they will gain in the experiment. For instance, if they are endowed with \$5 and lose \$2, they experience a gain of \$3 rather than experiencing a gain of \$5 and a separate loss of \$2. Under the wealth frame, PT makes essentially the same predictions as EU:

WEALTH HYPOTHESIS PT: If subjects are decreasingly risk-averse for gains, trades will take place at an indeterminate price.

Under the income frame, each gain from the receipt of a premium and each loss from the occurrence of a disaster is coded separately rather than being combined in some way. (For example, a gain of \$2 and a loss of \$5 are considered separately, rather than as a net loss of \$3.) In prospect theory, the value function for losses ($v(-x)$) is hypothesized to be steeper than that for gains ($v(x)$). This implies that firms will offer insurance at too high a price for consumers to afford, because firms receive less pleasure from earning premiums than consumers suffer from paying them (see appendix A).

INCOME HYPOTHESIS PT: No trades will take place.

This hypothesis is independent of the magnitudes of r and L. However, trade might conceivably occur if firms insure more than one ticket.[5]

The prospect theory analysis illustrates two points. First, it can make a big difference whether insurance is sold through an auction to consumers (as in McClelland, Schulze, and Coursey, 1986)[6] or through a double-oral auction between consumers and firms. In the double-oral auction, consumers must bid enough to satisfy firms (other subjects); under the income frame, they cannot possibly bid enough. (Of course, in natural markets firms probably have different utility functions than individuals do; trade might occur.) Second, prospect theory is rather awkward to apply, compared to expected utility theory. Predictions depend upon the choice of one of two different frames, and a choice of integration rule within one of those frames. Furthermore, Fischhoff (1983) found that it was difficult to predict which frame subjects would use in a simple choice experiment.

1.4. Competing theories of the effect of losses on prices

In their experiments, McClelland, Schulze, and Coursey (1986) found evidence of the *gambler's fallacy* in subjects' bidding behavior: bids began to rise after several periods without a realized loss, as if a loss was increasingly likely to occur. Irwin and Tolkmitt (1968) report similar results.

In our experiments, there are several potential losses each period because there are several consumers with one ticket each. If subjects believe in the gambler's fallacy, then periods with few losses will be followed by higher prices for insurance and periods with many losses will be followed by lower prices (as if losses are less likely for a while). When current prices are regressed against previous losses, a gambler's fallacy should cause a negative regression coefficient.

Gambler's Fallacy Hypothesis: Prices in period t will be *negatively* correlated with the number of losses in the previous period $t - 1$.

An alternative hypothesis is that recent losses are more available in memory (Tversky and Kahneman, 1973), temporarily increasing the subjective probability of current losses and raising prices. The concept of availability suggests a positive correlation between past losses and prices.

Availability Hypothesis: Prices in period t will be *positively* correlated with the number of losses in the previous period $t - 1$.

2. Experimental design

In our experiments, several *consumer* subjects are endowed each trading period with hazards called *tickets*. Tickets have a low probability r of yielding a substantial monetary loss L to whoever owns them (see table 2 for values of r and L).

Consumers may transfer their risky tickets to other subjects, called *firms,* by paying firms an insurance premium.[7]

Table 2. Design parameters for experimental insurance markets

Experiment no.*	Probability r	Loss L	EV = rL	No. of buyers	No. of sellers	No. of periods
1i	.2	−2000	400	4	6	15
2i	.2	−2000	400	4	6	20
3m	.2	−2000	400	4	6	20
4c	.2	−2000	400	4	8	20
	.3		600			10
5m	.3	−2000	600	4	6	30
6m	.5	−2000	1000	5	8	25
7c	.3	−2000	600	4	6	30
8c	.3	−2000	600	4	6	20
9c	.3	−2000	600	4	8	35
10c	.2	−2000	400	4	6	30
11ch	.2	−2000	400	3	6	30
12c	.1	−4000	400	3	5	35
13c	.01	−10,000	100	6	3	30

*i = inexperienced, c = context experience, m = mechanism experienced, h = high stakes (1 franc = \$.01).

2.1. Subjects

Subjects were undergraduates, recruited by solicitations in decision sciences and finance classes at the Wharton School, University of Pennsylvania. Most of these subjects knew little about insurance, though they were familiar with concepts of probability, expected value, and sometimes risk aversion. Each experiment is denoted by a number (representing chronological order) and a letter describing the experience of subjects in that experiment. Experiments are designated *i* if subjects were *i*nexperienced, *m* if subjects had been in other experiments using the double-oral auction *m*echanism, and *c* if subjects had been in earlier experiments in the insurance *c*ontext. (Note that *c* subjects are always *m* subjects too.)

The total number of subjects in each experiment ranged from 9 to 15. There were alwyas more consumers than firms, so that firms could insure more than one ticket if they wanted to.

2.2. Procedure

All subjects sat together in a classroom. Instructions (see appendix B) were read aloud to inexperienced objects. Experienced subjects read their instructions silently.

In each trading period, consumers were endowed with one ticket, and firms were endowed with no tickets. At the end of each trading period, random drawings from a bingo cage (with replacement) determined whether each ticket yielded a loss or not. Each ticket was resolved independently, as if the risks being insured were independent. (Allowing the risks to be correlated, as with natural hazards like floods and earthquakes, requires a simple change in procedure.)

In each period, a drawing from the first bingo cage containing ten balls numbered from 1 to 10 determined a column of a publicly displayed table with 10 columns and 40 rows of four-digit random numbers. We then drew balls (with replacement) from a different bingo cage containing 40 balls to determine from which row the random number was drawn. If the random number in the selected column and row was at or below an established threshold, the ticket lost; if above this threshold the ticket did not lose. For instance, if r was .2, then random numbers between 0 and 1999 were losses; numbers between 2000 and 9999 were not losses. The advantage of the random number table is that it shows subjects a large sample of *potential* realizations of the random draws, which helps make their subjective probabilities match the objective probability we intended to induce.[8] After the random numbers were drawn, all tickets expired; a new set of tickets, one for each consumer, was issued in the next period.

Trading periods lasted 1½ minutes. During the trading periods, subjects buy insurance voluntarily in a *double-oral auction:* consumers shout out *bids* (premiums they are willing to pay) and firms shout out *offers* (premiums they are willing to accept). Bids had to increase and offers had to decrease, until a mutually agreeable trade took place; then all previous bids and offers disappeared and the trading process started over. Each set of five trading periods was called a *market*. At the beginning of each market, consumers were endowed with 5000 *francs*, worth \$5.[9] Firms were endowed with 100,000 francs (\$100). Each franc was redeemable for \$.001 at the end of the experiment (or for \$.01 in the high-stakes experiment). Since the loss from a ticket was generally 2000 francs, an uninsured consumer who lost three times in a market became bankrupt. Bankrupt consumers were still endowed with tickets each period, but were not allowed to buy insurance until the next market.[10]

At the end of each five-period market, consumers and firms transferred their net earnings to a profit sheet. (Consumers were then endowed with 5000 francs and firms with 100,000 francs in the next market.)[11] At the end of the three-hour experiment, subjects added up their total profits and subtracted a fixed cost (which was predetermined by the experimenters, but not announced until the end). Subjects generally earned \$20–\$30.

Note that our subjects only lose money from the endowment they are given, not from their pockets. We do not know whether they will frame those losses as separate from their endowment (in the income frame) or as integrated with their endowment (in the wealth frame). There is evidence from choice experiments (e.g., Camerer, 1988), that most subjects regard actual losses of wealth given by experimenters as different from gains (e.g., losing \$5 from a \$10 stake is different than winning \$5)—they do not use the wealth frame. If our subjects do use the wealth frame, then we are not testing whether losses are more painful than gains are pleasurable (loss aversion), as prospect theory predicts. But we do not know how to test for loss aversion in an ethical way. (The committee that oversees our experiments with human subjects will not allow subjects to lose their own money.) Even if we cannot truly test the loss-aversion prediction of prospect theory, we can test its predictions about probability weighting by varying the loss probability.

3. Experimental results

Table 2 summarizes the design parameters in the 13 experiments we have conducted. There were many variations in subject experience, loss probability and amount, and ambiguity about loss probability. We operationalized ambiguity on the probability by using a discrete uniform probability distribution, symmetric around r. Thus if we wanted $E(r) = .20$, for instance, we made it equally likely for r to be 0, .10, .20, .30, and .40 in the ambiguity periods. (One of the subjects drew a ball from another bingo cage after the period ended to determine which of the values of r would apply when tickets were resolved.) We will discuss the nature of ambiguity and its impact on equilibrium in sections 4 and 5.

Mean prices in each trading period are plotted in figures 2–11. The figures show period numbers (below each graph), the probability of loss (in each figure caption), the fraction of tickets that were insured in each market, and the expected value (EV) of tickets (a solid line through each graph). When there is ambiguity about the loss probability to consumers, to firms, or to both sides, this is also noted on the graph.

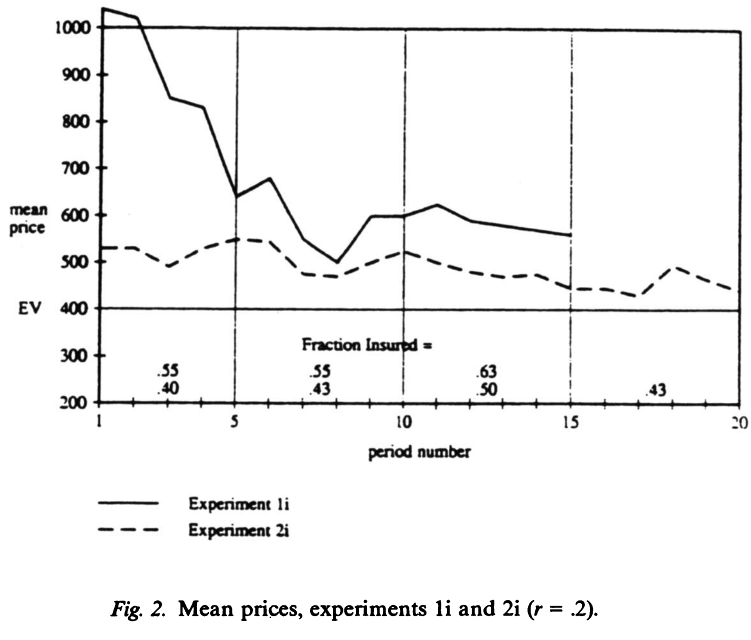


Fig. 2. Mean prices, experiments 1i and 2i ($r = .2$).

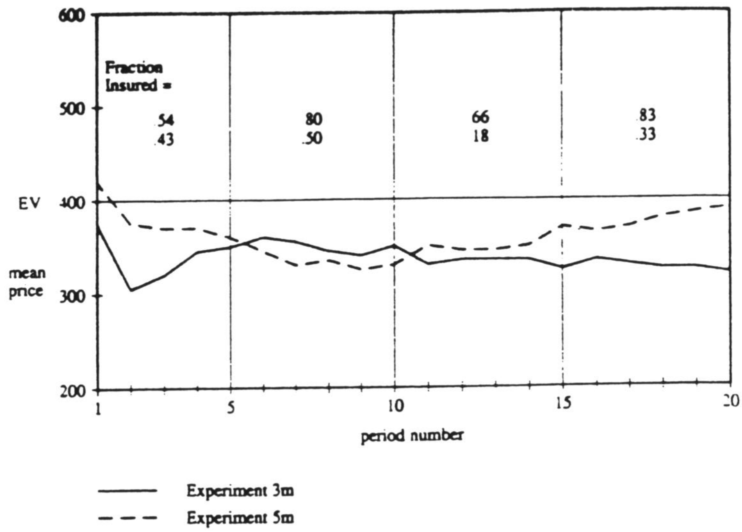


Fig. 3. Mean prices, experiments 3m and 5m (r = .2).

Prices eventually tend toward EV, though they often deviate from EV considerably for several periods. In the two experiments with inexperienced subjects (figure 2), prices start above EV and converge downward; experienced subjects (all other figures) typically start near or below EV. Prices are surprisingly close to EV in experiment 13c (figure 11), in which the loss probability was .01 and the amount of loss was 10,000 francs (or $10). (The two losses in that experiment, in periods 9 and 17, are marked on figure 11.)

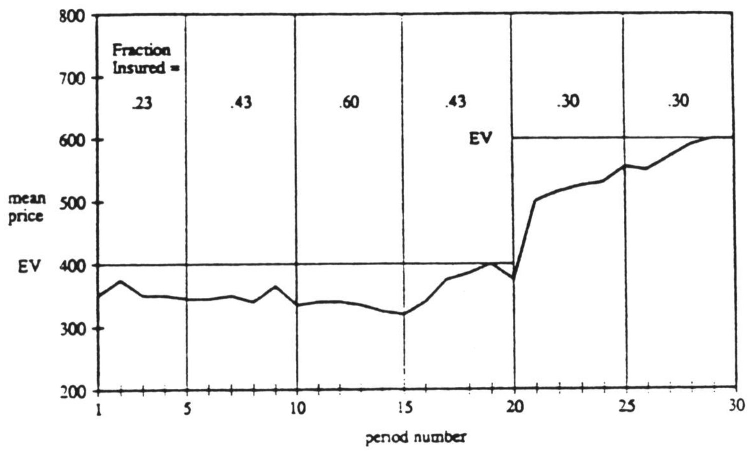


Fig. 4. Mean prices, experiment 4c (r = .2,.3).

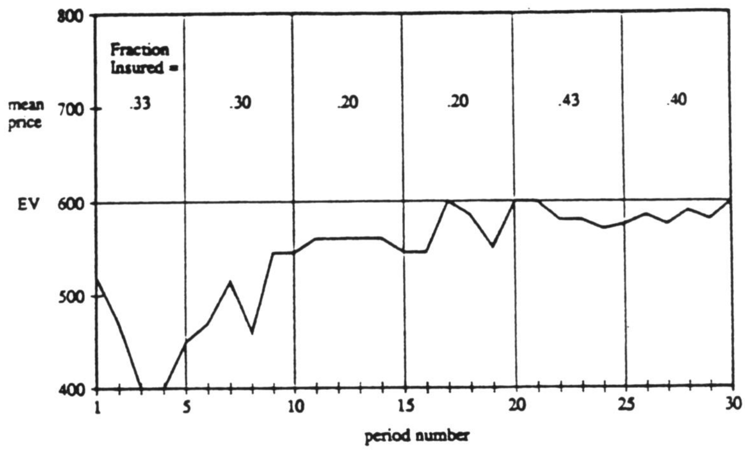


Fig. 5. Mean prices, experiment 6m (r = .3).

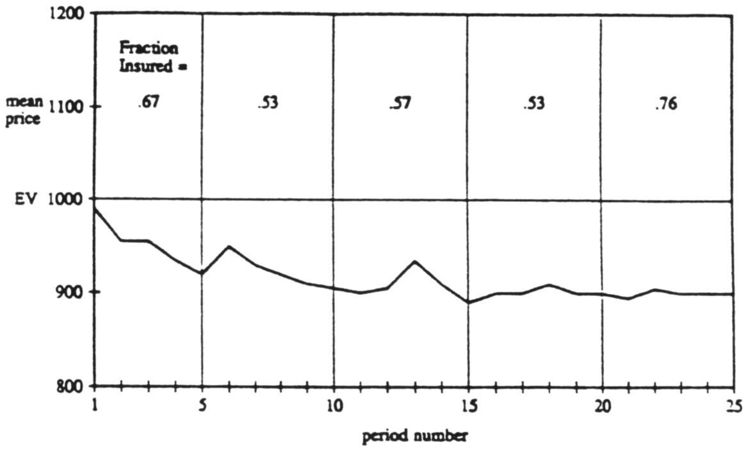


Fig. 6. Mean prices, experiment 7c (r = .5).

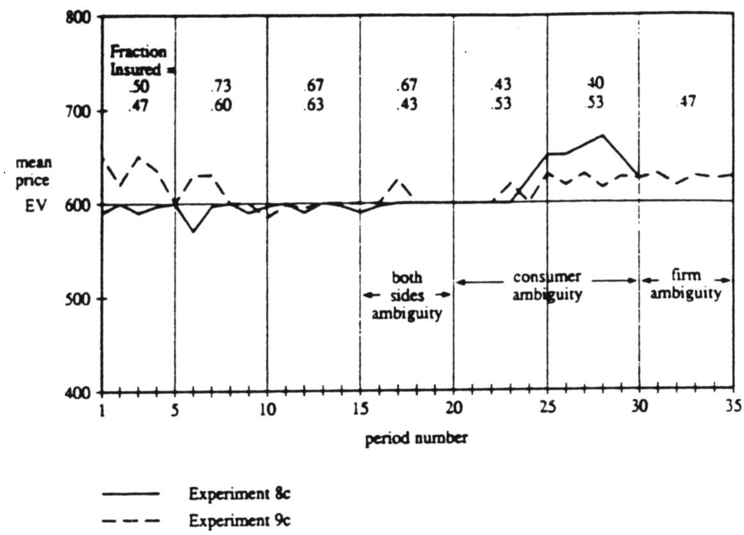


Fig. 7. Mean prices, experiments 8c and 9c (r = .3).

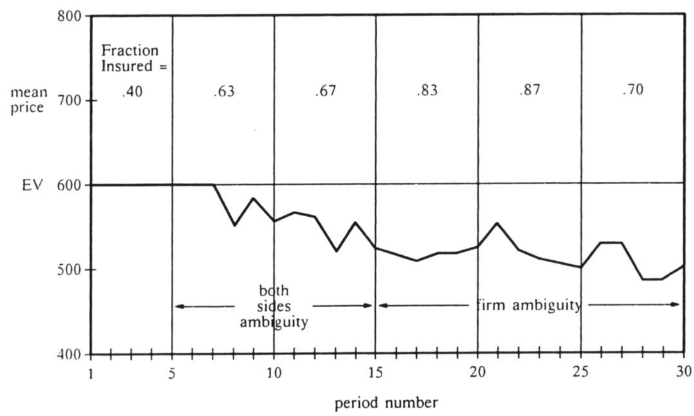


Fig. 8. Mean prices, experiment 10c (r = .3).

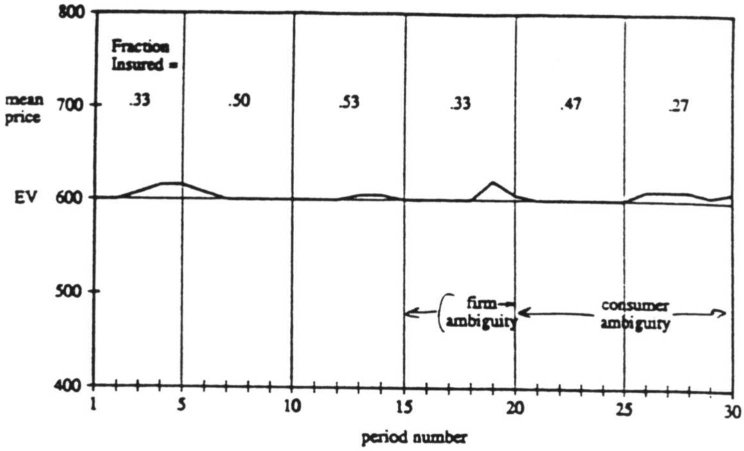


Fig. 9. Mean prices, experiment 11ch (r = .3).

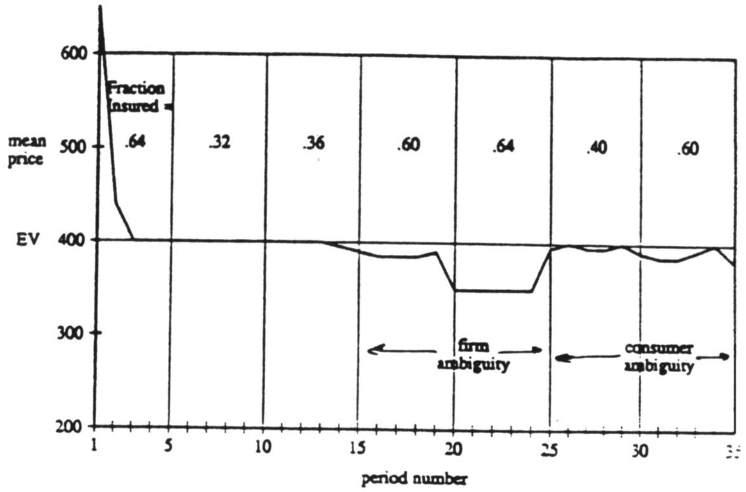


Fig. 10. Mean prices, experiment 12c (r = .1).

The fraction of tickets that are insured is fairly stable, averaging about 50%, both within and across experiments. In the experiments with ambiguity, prices are sometimes affected by ambiguity, but not in any consistent direction. For example, ambiguity seems to raise prices slightly in experiment 9c (figure 7), and lower prices in experiment 12c (figure 10).

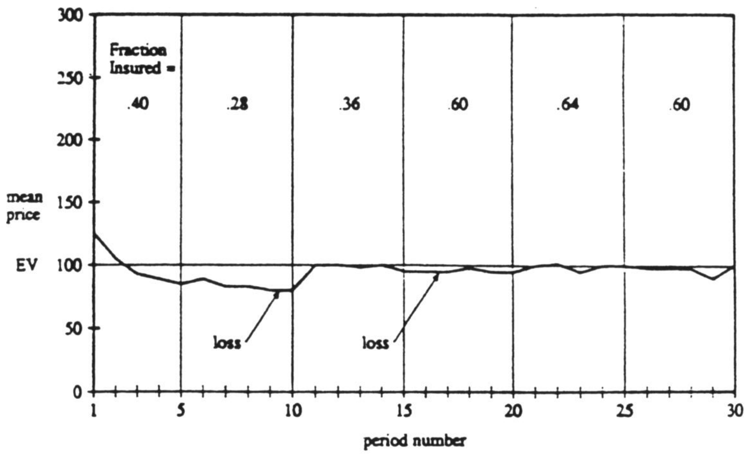


Fig. 11. Mean prices, experiment 13c (r = .01).

3.1. *Regression results*

To estimate equilibrium prices and the effects of past losses and ambiguity on prices, we regressed the mean price in each period (P_t) on 1) the previous period mean price (P_{t-1}),[11] 2) the number of losses in the previous period (L_{t-1}), and 3) 0–1 dummy variables for firm ambiguity (FA), consumer ambiguity (CA), and both sides ambiguity (BSA). Each dummy variable was set to 1 if that type of ambiguity was present in each period, and 0 otherwise. We thus estimated the regression coefficients in the equation

$$P_t = a + bP_{t-1} + cL_{t-1} + d\text{FA} + e\text{CA} + f\text{BSA} + z_t. \tag{3}$$

The parameter b is a measure of the rate of convergence. According to the simple specification (3), if prices are X francs from equilibrium in one period, the expected difference from equilibrium in the next period is bX francs. A value of b near 1 indicates slow convergence to equilibrium, while a value of b near zero indicates equilibrium. In other experimental contexts (Camerer, 1987), this simple model has worked reasonably well in describing adjustment of prices to equilibrium and removing statistical dependence from prices to allow formal test of hypotheses.

To calculate estimates of equilibrium prices we simply define equilibrium as $P_t = P_{t-1} = P$ (with $z_t = 0$), set FA = CA = BSA = 0, substitute the observed mean L' for L_{t-1} and observe that

$$P = a + bP + cL', \text{ or} \tag{4}$$

$$P = (a + cL')/(1 - b). \tag{5}$$

Thus, we can estimate P without bias by substituting the regression estimates of a, b, and c (and the sample mean of L_{t-1}) into equation (5). The standard error of the estimate of P can be calculated by a Taylor series approximation;[12] it is roughly the standard error of the estimate of a, divided by $1 - b$.

Ordinary least-squares (OLS) estimates of regression coefficients are shown in table 3. The last four columns present diagnostic statistics—adjusted R^2 (R-squared), sample size (N), the Durbin–Watson statistic (D–W), and the studentized range of regression residuals[13] (SR(e)). Since the Durbin–Watson statistics are near two, there is little serial correlation in the residuals. Residual studentized ranges suggest normality except in experiments 7c, 12c, and 13c; we should be cautious in interpreting t-statistics from those experiments.

Estimated equilibrium prices are indeed close to EV in all experiments, particularly in those using subjects with context experience (i.e., c experiments). For example, in experiments 8c through 11ch, the equilibrium price was within eight francs (8/10 of a penny) of EV. However, the standard errors are often so large that we cannot be very confident that prices are converging to EV.

3.2. Testing EU versus prospect theory

Recall the hypotheses presented in section 1: EU predicts that prices will be above (equal, below) EV if subjects are risk-averse (risk-neutral, risk-seeking). If subjects use the wealth frame, then prospect theory predicts trading at an indeterminate price. If subjects use the income frame, prospect theory predicts no trade.

Since nearly half the tickets were insured, those buyers and sellers who actually traded tickets were not consistent with the income frame hypothesis.[14] Prospect theory under the wealth frame can be tested against EU by comparing experiments with different probabilities and amounts of loss. In prospect theory, people are assumed to be risk-averse for gains, so premiums should always be above EV. In addition, low probabilities (e..g, less than .2) are assumed to be overweighted and higher probabilities are assumed to be underweighted. Therefore, according to prospect theory, the ratio of premiums to EV should be greater than one, and should increase as the probability of loss decreases. In EU, the ratio of premiums to EV depends only on the size of the loss.

Figure 12 shows the regression estimates of equilibrium premiums (divided by EV), with 90% confidence intervals around those estimates, averaged across all experiments with the same loss probability. The losses were \$2 in each experiment except experiment 13c (the leftmost point, $r = .01$, $L = \$10$) and experiment 12c ($r = .10$, $L = \$4$).

Prospect theory predicts the line connecting the estimated equilibrium prices should slope monotonically downward from left to right. EU predicts a flat line from $r = .2$ to $r = .5$, with a downward slope from $r = .01$ to $r = .1$ if subjects are decreasingly risk-averse. The line does slope slightly downward, from .1 to .2 but

Table 3. OLS regressions of mean prices against independent variables

Experiment*	EV p(loss)	Estimated equilibrium (standard error)	OLS regression coefficients (absolute t-statistics): Lagged prices: Lag 1	Lag 2	Lagged losses	Ambiguity dummy variables: Consumer	Firm	Both sides	R-squared	Diagnostic statistics: N	D-W	SR(e)
1i	400	550.1	.751		−18.19				.77	14	2.87	3.53
	.2	(320.9)	(6.71)		(.29)							
2i	400	481.9	.622		4.18				.26	19	1.90	2.95
	.2	(289.0)	(2.82)		(.31)							
3m	400	451.66	.485	−.174	−.01				.44	18	1.76	3.72
	.2	(94.1)	(3.35)	(1.58)	(.01)							
5m	400	370.1	.938	−.076	1.52				.56	18	2.06	3.48
	.2	(370.7)	(3.80)	(.46)	(.15)							
6m	600	557.3	.847		−4.97				.67	29	2.00	4.85
	.3	(391.2)	(7.66)		(.18)							
4c	400	356.7	.505		9.90				.97	29	1.85	3.51
	.2	(57.7)	(6.14)		(1.73)							
	600	570.9										
	.3	(65.9)										
7c	1000	907.0	.600		3.15				.53	24	2.52	4.94
	.5	(269.1)	(5.12)		(.73)							
8c	600	595.4	.609		−4.65	36.88		3.55	.75	29	1.82	4.14
	.3	(213.4)	(4.30)		(1.15)	(1.96)		(.26)				
9c	600	607.4	.295		2.78	5.16	12.60	−3.43	.04	34	2.21	4.66
	.3	(139.8)	(1.83)		(.96)	(.65)	(1.26)	(.34)				
10c	600	601.9	.355		−4.64		−91.89	−40.42	.75	29	2.50	4.51
	.3	(183.9)	(1.80)		(1.06)		(2.92)	(2.04)				
11ch	600	607.1	.430		.14		2.26	−3.33	.12	29	1.84	4.25
	.3	(200.0)	(2.29)		(.11)		(.80)	(.42)				
12c	400	438.8	.537	−.055	1.31	−5.13	−36.53		.70	33	1.71	5.58
	.1	(24.2)	(3.79)	(1.55)	(.40)	(.64)	(3.03)					
13c	100	91.9	.808	−.231	−4.26				.41	28	1.93	5.12
	.01	(26.0)	(4.08)	(1.59)	(.50)							

*i = inexperienced, c = context experience, m = mechanism experienced, h = high stakes (1 franc = \$.01).

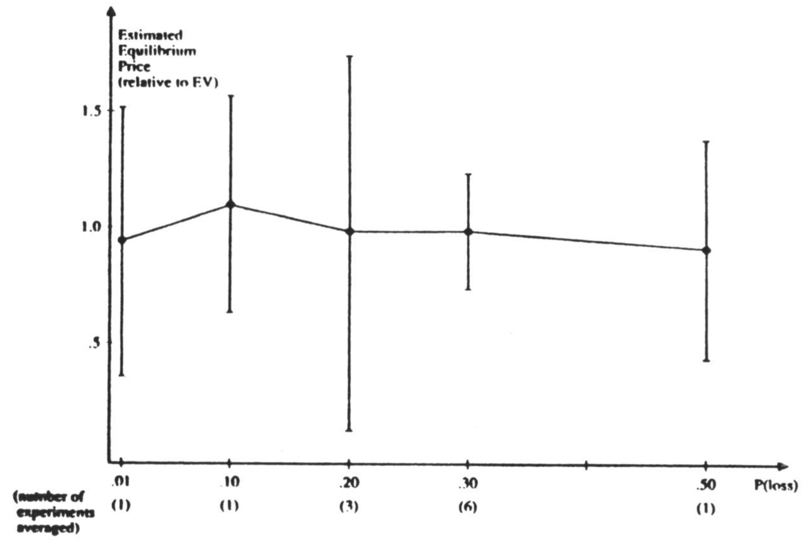


Fig. 12. Estimated equilibrium prices (with 90% confidence bounds) as a function of loss probability.

not from .01 to .1, but the confidence intervals are too wide for us to tell whether the line is flat or sloped. We do not see the strong support for prospect theory—high premiums for $r = .01$, due to overweighting of low-probability events—that was reported in McClelland, Schulze and Coursey (1986). This difference raises the question of how well prospect theory fares in market settings where there is repeated trading between buyers and sellers. Experience and competition in the double-oral auction may induce many people to obey the axioms of EU better or more swiftly than one-sided bidding mechanisms like the second-price auction. We believe this area merits more research. Perhaps the money amounts we used were too small to detect concavity in the gain function in prospect theory; but this question may be impossible to answer with experiments that are constrained by realistic grant budgets.

3.3. The effect of past losses

The gambler's fallacy hypothesis predicts that the coefficient on the lagged loss term in the regression will be negative; availability predicts a positive coefficient. The regression coefficients in table 3 are both positive and negative, with small *t*-statistics (shown in parentheses), suggesting no strong support for either theory.

We also examined patterns of insurance behavior after losses for evidence of gambler's fallacy or availability effects. For each consumer subject in each experiment, we constructed contingency tables with columns *insured in period* $t + 1$ and *didn't insure in period* $t + 1$ and rows *ticket lost in t* and *ticket didn't lose in t*.[15] If insurance behavior in $t + 1$ depends on losses in t, a chi-squared test will reject the hypothesis of independence in these contingency tables.

With the exception of one experiment, there were not enough data for each individual consumer in each contingency table cell to test for individual associations using a chi-squared test, because there were too few losses to provide enough observations in the *ticket lost in t* cell. Hence, for each experiment we pooled two sets of data across consumers: 1) subjects who were insured in period t, and 2) subjects who were not insured in t. This enabled us to use a chi-squared statistic to determine whether the gambler's fallacy was a function of whether consumers held tickets or insured them. There were 24 such statistics (experiment 13c did not provide enough data to make the test meaningful). Only one of the 24 statistics (6.35) was greater than the 95% fractile.

Since each experiment was independent, we can gain power by adding the chi-squared statistics. Under the null hypothesis of independence, their sum should have a chi-squared distribution with 24 degrees of freedom. The actual sum, 32.15, is close to the value expected under independence.

Independence might occur in the pooled data if half the consumers exhibit an availability effect (a positive association in the contingency table) and half exhibit a gambler's fallacy effect (a negative association). This hypothesis can be rejected by analysis of experiment 7c, which shows that each individual's past losses and insurance behavior are independent.[16]

In the earlier studies showing gambler's fallacy effects, subjects bid for a fixed supply of insurance (McClelland, Schulze, and Coursey, 1986) or for insurance at a fixed price (Irwin and Tolkmitt, 1968). Since we find no such effects, it is tempting to conclude that since prices adjust more quickly in double-oral auctions, the gambler's fallacy in holdings (quantity demanded) is eliminated by price changes.[17] But the regressions in table 3 showed that prices were *not* affected by past losses. Since both quantities and prices are independent of past losses, independence in our experiments seems to come primarily from subjects—even inexperienced ones—understanding that losses are statistically independent. Our practice of drawing several balls in each period (one for each ticket), rather than one each period as in the other studies, may also increase learning of independence.

4. The effect of ambiguity on insurance behavior

We now turn to the impact of probability ambiguity on market equilibrium. Below we present hypotheses about prices and quantities of insurance under ambiguity as predicted by expected utility theory, prospect theory and other recent theories. In Section 5 we summarize the results of our experiments when the probability of a loss was ambiguous to consumers, to firms, or to both sides.

4.1. Ambiguity

Many insurance markets are characterized by *uncertainty* or *ambiguity* (consumers or firms do not know loss probabilities), rather than by *risk* (consumers or firms know loss probabilities). The distinction between ambiguity and risk (see Knight, 1921) was well drawn by Ellsberg (1961). His thought experiments used a risky urn (*R-urn*) containing 50 red balls and 50 black balls, and an ambiguous urn (*A-urn*) containing 100 balls in some unknown proportion of red and black. Most people would agree that a drawing from the R-urn has $P(\text{red}) = .5$. One can apply the principle of insufficient reason to conclude that the *expected* probability of drawing a red ball from the A-urn is also .5—that is, if we imagine a probability distribution of the parameter $P(\text{red})$ (or a distribution of such distributions, ad infinitum), there is no reason it should not have a mean of .5.

To an expected utility maximizer, knowing that $E(P(\text{red})) = .5$, as in the A-urn, should yield the same choices as knowing that $P(\text{red}) = .5$, as in the R-urn (see, e.g., Raiffa, 1961, and section 4.3 below). However, Becker and Brownson (1964), Slovic and Tversky (1975), Yates and Zukowski (1976), MacCrimmon and Larson (1979), Gardenfors and Sahlin (1983), Kahn and Sarin (1988), Curley and Yates (1985), Einhorn and Hogarth (1985), and Curley, Yates, and Abrams (1986) have found that people do not bet identically on ambiguous and risky urns—typically, people display an aversion twoard ambiguity. (However, subjects' choices were only made for actual money in the experiments of Becker and Brownson (1964) and Curley et al.)

There has been much lively debate about whether it is *normatively* desirable to distinguish between ambiguity and risk. Our concern is purely *descriptive*. Ambiguity does seem to matter to subjects; and some researchers have specifically noted that ambiguity aversion might explain why insurance markets sometimes fail (e.g., Hogarth and Kunreuther, 1985; Bewley, 1986). Since it is difficult to test the effect of ambiguity on markets with natural data, we test it in several of our experiments by introducing ambiguity about the probability of losses in some trading periods.

4.2. Operationalizing ambiguity

We do not know of any fully satisfactory method to operationalize Ellsberg-style ambiguity in experiments. One potential problem is that subjects may think experimenters have loaded an urn or bingo cage with balls that yield unfavorable outcomes for subjects. A more difficult problem arises if we wish to conduct an experiment with repeated draws from an ambiguous urn or cage. Suppose we choose a second-order distribution of r denoted $f(r)$, then use $f(r)$ to generate a specific value r^* for r in period t, and use r^* to generate losses for tickets in period t. Since several tickets are resolved each period, subjects would learn a fair amount about r^* in period t, and across periods they could learn about $f(r)$ by observing the sample of estimates of r^*. If we used the same $f(r)$ throughout the experiment, their ambiguity would be reduced as the experiment continued. The effect of this reduction in ambiguity on prices could be confounded with convergence to equilibrium and other kinds of learning in the experiment. If prices converged to the expected value prediction from above, for instance, it could be because prices converged that way in general, or because reduction in the degree of ambiguity caused the equilibrium price to fall.

Because of the impossibility of operationalizing true Ellsberg-style ambiguity, we used a simpler kind of ambiguity—a discrete-uniform probability distribution, symmetric around r as described at the beginning of section 3. Discrete-uniform ambiguity is not as dramatic as Ellsberg's, but it is easy to operationalize, and it provides a lower bound for ambiguity effects: if we observe aversion to discrete-uniform ambiguity in our markets, then aversion to Ellsberg-style ambiguity seems quite likely. Furthermore, Yates and Zukowski (1976) found that subjects were averse to discrete-uniform ambiguity.

Since the theories considered below predict that ambiguity will have different effects on consumers and firms, we varied which type of subjects' loss probabilities were ambiguous each period. We always announced whether consumers or firms had ambiguous loss probabilities before each trading period began.

4.3. Expected utility under ambiguity

Since expected utilities are linear functions of outcome probabilities in EU theory, ambiguity should not matter to consumers, or to firms who insure one ticket. To see this, suppose the loss probability r has a continuous distribution $f(r)$ over the range $[a,b]$. Then the expected utility under ambiguity is $\int_a^b f(r)u(-L)dr$. Since $u(-L)$ does not depend on r, this reduces to $u(-L)\int_a^b f(r)dr$, or $E(r)u(-L)$. Thus, only the mean of the distribution $f(r)$ matters for EU maximizers. (Indeed, the same is true for anyone obeying the reduction of compound lotteries axiom implicit in *most* choice theories, including generalizations of EU.)

However, if firms are risk-averse and insure more than one ticket, ambiguity can matter under EU. For example, a firm that insures two tickets, each with a known probability of r, earns an expected utility of

$$EU(2\text{ tickets, risk}) = r^2U(2P - 2L) + 2r(1 - r)U(1P - L) + (1 - r)^2U(2P). \tag{6}$$

For simplicity, suppose that ambiguity means the tickets are equally likely to have a loss probability of 0 or $2r$. Then the expected utility of a firm who buys two tickets is

$$EU(2\text{ tickets, ambiguity}) = 2r^2U(2P - 2L) + 2r(1 - 2r)U(2P - L) + (1 - 2r + 2r^2)U(2P). \tag{7}$$

Since *EU*(2 tickets, ambiguity) has more probability on the extreme outcomes $U(2P - 2L)$ and $U(2P)$ than *EU*(2 tickets, risk) does, ambiguity causes a mean-preserving spread of outcomes. If firms are risk-averse (risk-seeking) they will dislike (prefer) a mean-preserving spread and therefore charge a higher (lower) insurance premium under ambiguity than under risk.

Since ambiguity does not affect consumers' reservation prices according to EU, a shift in the supply curve caused by ambiguity among firms (or among both consumers and firms) will increase prices and decrease quantity if firms are risk-averse, or decrease prices and increase quantity if firms are risk-seeking.

Ambiguity Hypothesis EUra: If firms are risk-averse, ambiguity about loss probabilities by firms and consumers will cause higher prices and a lower quantity of trade if and only if firms insure more than one ticket. If firms insure only one ticket, ambiguity about loss probabilities will not affect prices or quantities.

Ambiguity Hypothesis EUrs: If firms are risk-seeking, ambiguity by firms about loss probabilities will cause lower prices and a higher quantity of trade if and only if firms insure more than one ticket. If firms insure only one ticket, ambiguity about loss probabilities will not affect prices or quantities.

4.4. Prospect theory under ambiguity

Prospect theory does not explicitly discuss how ambiguity would be handled, because probabilities are not always compounded as they are in EU (e.g., the *isolation effect,* Kahneman and Tversky, 1979, p. 271). However, Kahneman and Tversky (1979) do note that "... the work of Ellsberg (1961) and Fellner (1961) implies that vagueness *reduces* decision weights" (our emphasis). Assuming that a reduction in decision weights due to ambiguity affects consumers and firms identically (cf. Einhorn and Hogarth, 1985), prospect theory under the wealth frame would predict that bids and offers decrease under ambiguity.[18]

Wealth Frame Ambiguity Hypothesis PT: Ambiguity about loss probabilities will decrease prices. Consumer ambiguity will decrease the quantity of trade, and firm ambiguity will increase the quantity of trade.

4.5. Other theories of ambiguity aversion

Several recent theories seek to explain why people are ambiguity-averse, and we can apply some of these theories to our market setting.

Segal (1987) seeks to explain the Ellsberg paradox with the *anticipated* utility theory of Quiggin (1982) and Yaari (1987) (which is also called *dual EU,* or *EU with rank-dependent probabilities*). In anticipated utility theory, risk aversion is the systematic overweighting of the probabilities of the worst outcomes in a lottery (and underweighting of the best outcomes), with marginal utility held constant. Because risk aversion is located in probability weights, rather than in the shape of the utility function (or possibly in both places; see Chew, Karni, and Safra, 1987), aversion to ambiguity is a simple extension of aversion to risk. With gambles involving losses, Segal shows that probability weights of potential losses will be increased under ambiguity, which implies higher prices in our insurance markets. Smith (1969) makes a similar conjecture.

> ***Segal Ambiguity Hypothesis:*** Ambiguity about loss probabilities will increase prices. Consumer ambiguity will increase the quantity of trade, and firm ambiguity will decrease the quantity of trade.

Many other recent theories model ambiguity aversion. Most of these theories define ambiguity as the inability to rule out distributions of probability (e.g., Einhorn and Hogarth, 1985; Gardenfors and Sahlin, 1983). Each theory then relaxes restrictive choice axioms (Bewley, 1986), perhaps invoking additional parameters (see *confidence weights* in Nau, 1986, or Kahn and Sarin, 1987), to measure the degree of or attitude toward ambiguity.

If ambiguity is a multiplicity of distributions, then the kind of ambiguity in our experiments should not matter because subjects can rule out all distributions of the loss probability except for one (the discrete-uniform distribution). Thus, Segal's theory (and Smith's conjecture) are the only ambiguity aversion theories being tested by our data. In further research, we hope to operationalize Ellsberg ambiguity in order to test other theories of ambiguity aversion.

Table 1 summarizes the predictions of EU, prospect theory, and Segal ambiguity about prices and quantities.

5. Experimental tests of ambiguity

5.1. The effects of ambiguity

The effects of ambiguity are shown in figures 7 through 10, and measured by dummy variables in the price regressions reported in table 3. The effects of ambiguity are rather minor and mixed. The dummy-variable regression coefficients in table 3 have different signs, and are usually insignificant. The only effect worth mentioning is caused by firm ambiguity, where two of the four coefficients are significantly negative.

The insignificant price effect of consumer-only ambiguity and a negative effect of firm-only and both-sides ambiguity is consistent with the increasingly risk-seeking EU hypothesis, which predicts lower prices, more quantity, and a higher number of tickets insured per firm. The data are not consistent with the wealth frame hypothesis or Segal's hypothesis (see table 3).

Ambiguity also had some small effects on the quantity of tickets insured. Pooling across all experiments, firm ambiguity caused a relatively large increase in the fraction of tickets insured, from 48.1% to 61.3%.[19] This difference is highly significant by a normally approximated binomial test ($z = 2.99, p < .01$). (Consumer and both-sides ambiguity also changed the fraction of tickets insured insignificantly, from 52.8% to 45% and 57.1% to 60%, respectively.) The increase in quantity traded under firm ambiguity is consistent with both EU and PT (under the wealth frame). However, the lack of effect when both sides are ambiguous goes against the EU prediction.

Ambiguity also affected the number of tickets insured by each active firm (a firm insuring any tickets). In firm and both-sides ambiguity periods, the number of tickets per firm rose from 1.53 to 2.03 and from 1.56 to 1.79, respectively. These increases support EU because EU specifically predicts that ambiguity affects prices only if firms insure more than one ticket. However, the number of tickets per active firm also rose during consumer ambiguity (from 1.46 to 1.71).

Certainly, the argument that ambiguity cripples insurance markets receives little support from our data, though the kind of ambiguity we used is simpler than the Ellsberg-type ambiguity (which is of more theoretical and practical interest).

6. Conclusions and further research

Insurance is a paradigmatic example of decision making under uncertainty, but natural insurance data are complicated by information asymmetries, regulation, and other factors. We have studied insurance buying and selling in an experimental setting with complicating factors omitted.

In the experiments, each of several consumers are endowed with tickets that may yield a loss L with probability r. Other subjects, called firms, may absorb the risks of those ticket losses from consumers in voluntary exchange for an insurance premium, which is determined in a double-oral auction.

One of our purposes was to see if the double-oral auction, which has been used in hundreds of experiments involving gains, reaches a reasonable equilibrium when subjects trade claims that yield losses. Our markets clearly do converge to stable prices (especially with experienced subjects), with a substantial amount of trading. There seems to be nothing special about risky losses, even 1% chances of $10 losses, that disturbs the effectiveness of the double-oral auction in facilitating exchange.

Our second purpose was to compare expected utility theory and a competing theory of choice, prospect theory (Kahneman and Tversky, 1979), in their predictions about market equilibrium. Market prices were close to expected value in all experiments, consistent with expected utility maximization by approximately risk-neutral subjects. Since prospect theory has more degrees of freedom than EU—in its value function, decision weight function, and choice of subject frames—it is not clearly rejected by our data, but we found little evidence specifically supporting prospect theory over EU. The strongest evidence is that prices were close to expected value in a wide range of experiments with different loss probabilities. Either subjects were not weighting probabilities nonlinearly (as prospect theory predicts), or repetition of gambles made decision weights closer to linear than they would be for individual choices.

In contrast to some earlier studies, we also found that when past losses were infrequent, people did not succumb to either a gambler's fallacy—believing losses were increasingly likely—or an availability bias—believing losses were unlikely. Our subjects seemed to realize that random draws are truly independent.

Our third purpose was to study the market effects of a simple type of ambiguity about probabilities, in which the probability of a hazard loss (r) is unknown. To create ambiguity, we generated loss probabilities according to a discrete-uniform probability distribution—e.g., r is equally likely to be 0, .1, .2, .3, or .4, instead of $r = .2$ with certainty. There are some empirical and theoretical reasons to expect that people will be averse toward ambiguity of this type, and it is easy to operationalize. (Ambiguity in which r is truly uncertain is virtually impossible to operationalize in a repeated setting.) Discrete-uniform ambiguity had little effect on market prices in our experiments. The biggest effects occurred when firms were ambiguous about loss probabilities: prices dropped, the quantity of tickets insured increased, and the number of tickets insured by each firm increased. These effects are consistent with EU maximization if firms are slightly risk-seeking.

A promising avenue for future research is to operationalize other types of ambiguity about probabilities, and allow wider ranges of losses, in the context of insurance markets. Many of the current market failures in insurance (e.g., environmental pollution liability and medical malpractice) appear to be due to uncertainty about probability *and* fear about potential losses. In addition, there may be information asymmetries between firms and consumers regarding either the probabilities or the outcomes, a fact that can create adverse selection problems (e.g., Akerlof, 1970). One may also want to determine experimentally how much consumers and firms would be willing to pay for more precise information on either probabilities or losses before engaging in trade (e.g., Schoemaker, 1987). This is an ambitious agenda, but one that we feel is worthwhile given the current crises in real-world insurance markets and our need to understand more fully the causes of these problems.

Acknowledgments

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Appendix A. Wealth and income frames: Hypotheses regarding trade

A.1. Wealth frame

Figure 13a depicts the relevant tradeoffs for consumers under the wealth frame. (Throughout the analysis, we assume all subjects have identically shaped value and decision weight functions, since assuming otherwise allows virtually any market-level behavior.) If consumers insure, their endowment has a certain value $v(W_c - P)$. If they do not insure, they face a prospect with an r chance of $v(W_c - L)$ and a $1 - r$ chance of $v(W_c)$. In PT, prospects with two positive outcomes X and Y with probabilities r and $(1 - r)$ (with $X < Y$, say) are valued as a sure gain component $v(X)$ and an additional gain component, $v(Y - X)$ with weight $\pi(1 - r)$. Therefore, by not insuring, consumers would earn a weighted value $v(W_c - L)$ (the sure gain from not insuring) plus $\pi(1 - r)v(L)$. Under the wealth frame of PT, consumers' reservation prices P_c^* thus solve

$$v(W_c - P_c^*) = v(W_c - L) + \pi(1 - r)v(L). \quad (8)$$

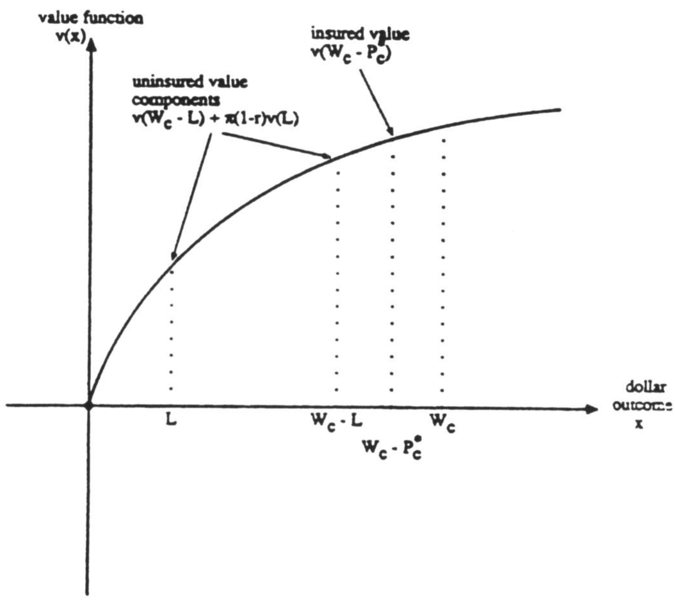

Fig. 13a. Consumer's choice, wealth frame.

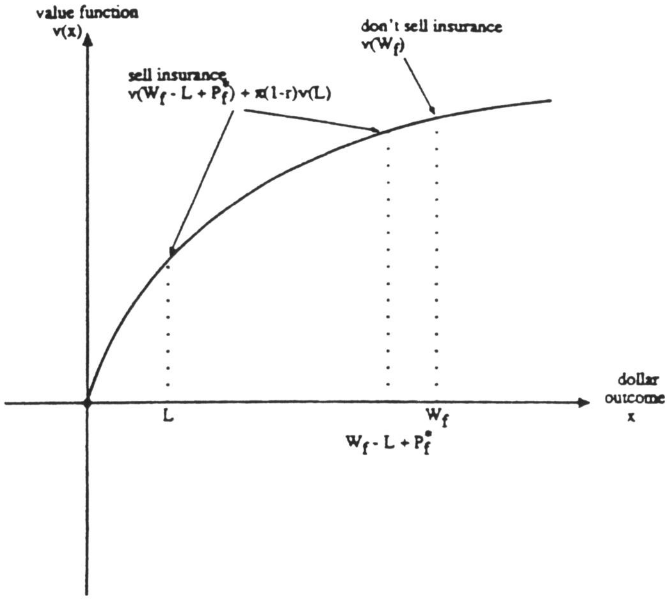

Fig. 13b. Firm's choice, wealth frame.

The gain $v(L)$ is likely to be underweighted, since $1 - r$ ranges from .5 to .99, in our experiments, and high probabilities are underweighted in PT; hence the prospect of going uninsured is relatively unattractive, so equation (8) seems to predict reservation prices P_c^* above expected value.

Under the wealth frame, as shown in figure 13b, firms can insure and earn $v(W_f - L + P_f) + \pi(1 - r)v(L)$, or they can not sell insurance and earn $v(W_f)$. Firms' reservation prices P_f^* thus solve

$$v(W_f) = v(W_f - L + P_f^*) + \pi(1 - r)v(L). \tag{9}$$

As with EU analysis, we can see from comparing equations (8) and (9) that there will be trading between firms and consumers (i.e., $P_f^* < P_c^*$) if subjects' value functions for gains are decreasingly risk-averse, since $W_f > W_c$.

An example: Suppose the value function is $v(x) = (x)^{.95}$ (which exhibits decreasing absolute risk aversion). Assume $W_C = 10{,}000$, $W_f = 100{,}000$, $L = 2000$, $r = .2$, and $\pi(1 - r) = .6$. (Note that the decision weight attached to $1 - r = .8$ is less than the objective probability of .8.) Plugging into equations (8) and (9), we find $P_c^* = 641$ and $P_f^* = 465$. Therefore, the equilibrium price P^* will be somewhere between 465 and 641.

A.2. Income frame

Under the income frame, consumers can insure and suffer a sure loss with value $v(-P_c)$, or they can forego insurance and have a prospect with weighted value $\pi(1 - r)v(0) + \pi(r)v(-L)$, which is simply $\pi(r)v(-L)$, since $v(0) = 0$ by assumption.

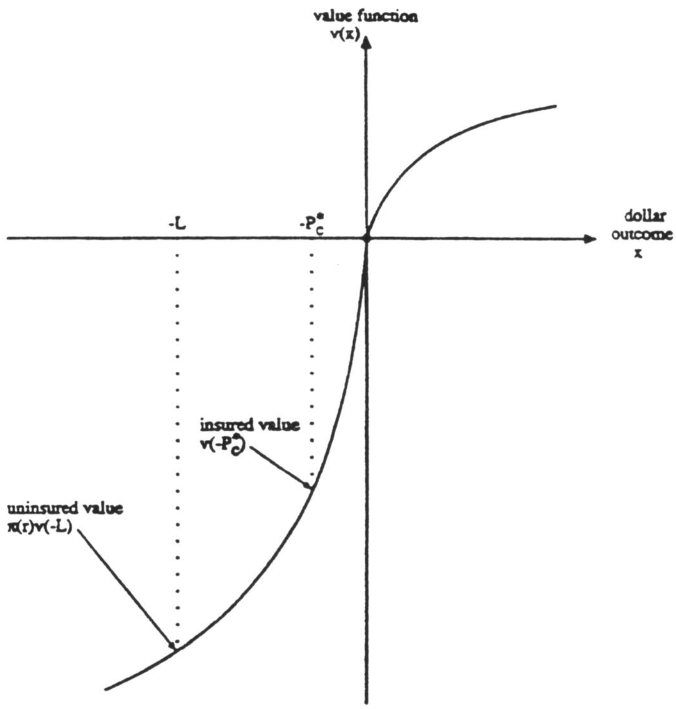

Fig. 14a. Consumer's choice, income frame.

As shown in figure 14a, consumers' reservation prices P_c^* thus solve

$$v(-P_c^*) = \pi(r)v(-L). \tag{10}$$

Under the income frame, firms choose between $v(0)$ (not selling insurance) and an insurance prospect that earns a certain $v(P_f)$ along with a weighted value $\pi(r)v(-L)$, as illustrated in figure 14b.

Firms reservation prices P_f^* then solve

$$v(0) = v(P_f^*) + \pi(r)v(-L), \tag{11}$$

or

$$-v(P_f^*) = \pi(r)v(-L).$$

The reservation prices of firms and consumers are related in a simple way: $-v(P_f^*)$ for firms must equal $v(-P_c^*)$ for consumers, because both are equal to $\pi(r)v(-L)$, by equations (10) a..u (11). Because losses are generally steeper than gains, PT therefore predicts that P_f^* will be greater than P_c^* and no trades will take place.[20]

An example: Consider the wealth frame example above with the additional assumptions that $\pi(.2) = .2$ and $v(-x) = -(x)^{1.02}$. Then equations (10) and (11) yield $P_c^* = 413$ and

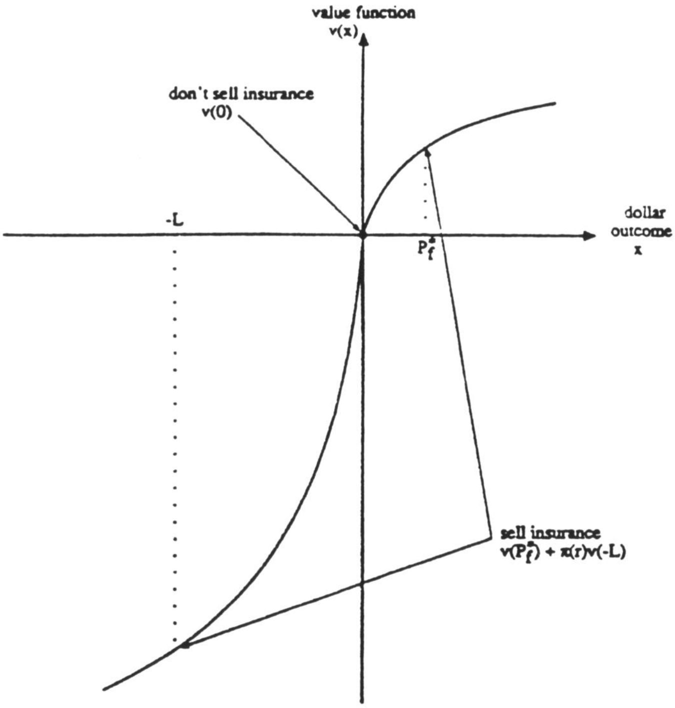

Fig. 14b. Firm's choice, income frame.

$P_f^* = 643$. Consumers will not pay enough to satisfy firms, because gains (premiums earned) are concave and losses (premiums paid) are convex. If loss functions are steeper than gain functions (e.g., $v(x) = (x)^{.95}$ and $v(-x) = -a(x)^{1.02}$ with $a > 1$), then the disparity between P_c^* and P_f^* will be even greater.

Appendix B. Instructions to subjects

BUYER __________

1.0 General

This is an experiment in the economics of market decision making. Various research foundations have provided funds for this research. The instructions are simple, and if you follow them carefully and make good decisions you can finish the experiment with a considerable amount of money, which will be paid to you in cash.

In this experiment we are going to create markets with two types of participants who will be trading for tickets. Buyers will have the opportunity to increase their number of tickets and sellers will have the opportunity to decrease their numbers of tickets. The rules and procedure governing the trading of these tickets will be explained to you below.

The type of currency used in this market is francs. All trading prices and ticket losses will be in terms of francs. Each franc is worth *$.001* to you, so 1000 francs is worth *$1*. At the end of the experiment your francs will be adjusted and converted to dollars at this rate, and you will be paid in dollars. Notice that the more francs you earn, the more dollars you earn.

2.0 Buyer instructions

During the next three hours, we will create a sequence of different markets, each one consisting of five two-minute periods. At the beginning of each market you will be endowed with 100,000 francs. These represent your francs on hand for that market. At the beginning of each period, sellers will be endowed with one ticket, which has a chance of losing 2000 francs and a chance of losing nothing. You can increase your endowment of tickets by buying tickets from a seller at a mutually agreed-upon price. Your endowment of francs will then be increased by the transaction price. This is the number of francs you require from a seller to hold a ticket. The first time you buy a ticket, record the seller's number in row 1, column 1 of your Information and Record Sheet (see sample on page 1 of attached sheets) and the transaction price for this ticket in row 1, column 2.

Tickets you purchase can reduce your francs on hand at the end of a period. Each additional purchased ticket is recorded in a similar manner. To determine the outcome of a particular ticket, we will simply examine the number in a specific row and column of a random number table like the one displayed on the overhead in the front of the room. For example, consider a particular row and column. If this number is between 0 and 1999, then you lose 2000 francs; if the number is between 2000 and 9999, you lose nothing. For example, for row 10, column 3, the number is 3914 and you lose nothing; for row 11, column 3, the number is 504 and you lose 2000 francs.

At the end of each period, we will use a different random number table to determine the outcomes for each ticket. The specific rows and columns to be used will be determined by drawing balls from bingo cages. First, one of the 10 columns will be selected by drawing a ball from a bingo cage that contains 10 balls numbered from 1 to 10. One of the 40 rows will be selected by drawing a ball from a bingo cage that contains 40 balls numbered from 1 to 40. After the outcome of a ticket is determined, the balls will be replaced in both bingo cages.

The outcome of each ticket (0 or −2000) you acquired during a specific period is recorded next to the appropriate seller number in row 1, column 3 of your Information and Record Sheet. This amount is then added to the transaction price (column 2) and recorded in column 4. This is your net francs from purchasing this ticket. Add the net francs from all tickets bought to obtain the total net francs from purchased tickets, and record this amount in row 2, column 4 of next period's Information and Record Sheet. It represents your francs on hand at the beginning of the next period. The same procedure for recording transactions will be followed after every period.

3.0 Market organization

The market will be conducted in a series of periods. Each period will last for two minutes. All transactions are for one ticket at a time. Any buyer wishing to buy a ticket is free to raise his or her hand and make a verbal bid to buy one ticket at a specified price, and any seller with a ticket to sell is free to accept or not accept the bid. Any seller wishing to sell a ticket is free to raise his or her hand and make a verbal offer to sell one ticket at a specified price. Buyers and sellers must identify themselves by their trader number written in the upper right-hand corner of each information and record sheet. Remember that a buyer gains the transaction price, while a seller loses the transaction price. A seller cannot bid more than the number of francs on hand at the beginning of the period.

If a bid or offer is accepted, a binding contract has been closed for a single ticket, and the contracting parties will record the transaction on their Information and Record Sheets. Any ties in acceptance bids will be resolved by random choice. During the entire process, you are not to speak to any other subject. There are likely to be many bids and offers that are not accepted, but you are free to keep trying. You are free to make as much profit as you can.

At the end of each market (each five-period sequence), record the amount of francs on hand on your Profit and Loss Sheet (see sample on page 2 of attached sheets). Should your francs on hand go to zero before the end of the five-period sequence, you are declared bankrupt for this particular market. Record the negative amount of francs in the Profit and Loss Sheet for that market. Persons who are bankrupt reenter the experiment at the start of the next market.

At the end of the experiment, add your francs on hand recorded on the Profit and Loss Sheet for each market to obtain total francs. An adjustment will be made for all the buyers and an adjustment will be made for all sellers. Your francs will then be converted to dollars at the rate specified on page 1. You will be paid this amount in cash.

The first period will be a trial period and will not affect your profits. Use your sample sheet for this purpose.

2.0 Seller instructions

During the next three hours we will create a series of different markets, each one consisting of five two-minute periods. At the beginning of each market, you will be endowed with a fixed number of francs. These represent your francs on hand for that market. At the beginning of each period, you will be endowed with one ticket, which has a chance of losing 2000 francs and a chance of losing nothing. Tickets can reduce your francs on hand if you hold them at the end of a period. You can dispose of your ticket by selling it to a buyer at a mutually agreed-upon price. Your endowments of francs will then be decreased by this transaction price to determine the outcome of a particular ticket. We will examine the number in a specific row and column of a random number table like the one displayed on the overhead in the front of the room. For example, consider a particular row and column. If this number is between 0 and 1999, then you lose 2000 francs; if the number is between 2000 and 9999, you lose nothing. For example, for row 10, column 3, the number is 3914 and you lose 0. For row 11, column 3, the number is 504 and you lose 2000 francs.

At the end of each period, we will use a different random number table to determine the outcomes for each ticket. The specific rows and columns to be used will be determined by drawing balls from bingo cages. First, one of the 10 columns will be selected by drawing a ball from a bingo cage that contains 10 balls, numbered from 1 to 10. One of the 40 rows will be selected by drawing a ball from a bingo cage that contains 40 balls numbered from 1 to 40. After the outcome of a ticket is determined, the balls will be replaced in both bingo cages.

If you have not sold your tickets at the end of a period, the outcome is recorded by you in row 2, column 1 of your Seller Information and Record Sheet (see sample on page 1 of attached sheets). If your ticket is sold, record the transaction price (as a negative amount) in row 3, column 1 of this same sheet.

Your end of period francs on hand is determined in one of the following ways:

If you did not sell your ticket, add the ticket loss (0 or −2000) to the initial francs. If you sold your ticket, add the transactions price to the initial francs. Record your end of period francs in row 4, column 1. Transfer this amount to row 1, column 1 of next period's Information and Record Sheet. The same procedure for recording transactions will be followed after every period.

Notes

1. In double-oral auction experiments, neither consumers nor firms are actually price-takers. We assume they are to obtain equilibrium prices without having to solve the very complicated game subjects are playing.

2. In a natural market, firms are consortia of people, who are risk-neutral toward any one loss because its impact is small when divided among them. Then the competitive price would be set at the expected loss; all risk-averse consumers would buy insurance. Our experiments are different because we do not expect the subjects acting as firms to be risk-neutral.

3. By only purchasing $1/n$th of any ticket, the loss from a single disaster can be reduced significantly. As long as each disaster is independent of the others, the consumer is in the same position as a firm is when it purchases a large number of policies that are independent.

4. As the number of policies a firm sells increases (decreases, stays the same), then the reservation price will increase (decrease, stay the same) if the firm is risk-averse (risk-taking, risk-neutral).

5. If a firm buys two tickets, for instance, then it earns weighted value $\upsilon(2P) + \pi(2r(1 - r))(-L) + \pi(r^2)\upsilon(-2L)$. If r is large enough that r^2 is not overweighted, firms might charge a low enough P^* to make insurance affordable to consumers, since by convexity of losses $\upsilon(-2L)$ is not much worse than $\upsilon(-L)$.

6. McClelland, Schulze, and Coursey (1986) studied incentive-compatible *second-price auctions* (or *Vickrey auctions;* Vickrey, 1961) for insurance in which the highest bidder pays the second-highest price. Their results for low-probability losses are better explained by prospect theory than by expected utility theory.

7. In the experiments, consumers were called *sellers,* and were told they could sell tickets for a negative price to *buyers* (firms) (see the instructions in appendix B). After a period or two, subjects become accustomed to buying and selling at negative prices. We used these terms to avoid nonmonetary connotations or demand effects associated with the idea of insurance, which diminish our control over subjects' incentives.

8. In other experiments, subjective probabilities are sometimes controlled by performing several practice draws from a bingo cage, but our loss probabilities were often quite low, so we needed to provide larger samples—like the 400 potential draws shown by a random number table—to induce subjective probabilities reliably.

9. Francs have been used in many experimental studies. In our experiments, their chief advantage is that they induce more precise trading than dollars because subjects prefer to trade at round-numbered amounts, like \$.95 or \$1.00. When trading in francs, subjects might round to the nearest 5 or 10 francs, which is the nearest half-penny or penny.

10. Experiment 13 differed from the others in having a low-probability ($p = .01$) high-loss event ($-10{,}000$ francs). Consumers were endowed with 7000 francs at the beginning of each market.

11. In some experiments, we included a second lag of prices, P_{t-2}, to reduce the serial correlation in residuals after P_t was regressed against the first lag P_{t-1}.

12. To approximate the standard error of the estimate of P, we can take a Taylor series of the estimate of P around its mean. Denoting estimates of population parameters with primes (e.g., a' is the estimate of a), we get $P' = P + (a' - a)/(1 - b) + (a + cL')(b' - b)/(1 - b)^2 + L'(c'-c)/(1 - b)$. Since $V(P') = E((P' - P)^2)$, using the Taylor-series approximation gives $V(P') = V(a')/(1 - b)^2 + V(b')(a + cL')^2/(1 - b)^4 + V(c')L'^2/(1 - b)^2 + 2(a + cL')\mathrm{cov}(a',b')/(1 - b)^3 + 2L'\mathrm{cov}(a',c')/(1 - b)^2 + 2L'(a + cL')\mathrm{cov}(b',c')/(1 - b)^3$. In practice, approximating $V(P')$ with just the first term $V(a')/(1 - b)^2$ gives a value of $V(P')$ within a couple of percent of the full approximation.

13. The studentized range of a sample is the difference between the maximum and minimum observations divided by the estimated population standard deviation. Studentized range is sensitive to both skewness and kurtosis in a sample, so it is a robust single-statistic test for violations of normality that may bias t-tests of regression coefficients. If residuals are normally distributed, studentized ranges will be between 3.25 and 4.27 (if $n = 19$) and 3.68 and 4.83 (if $n = 34$) 90% of the time.

14. It is possible that those who did trade tickets felt some pressure to do so because they were participating in the experiment (a *demand effect*). To the extent that this was true, then such individuals could be consistent with the income frame hypothesis of prospect theory.

15. We made separate tables for periods in which subjects were insured in t, and another table for periods in which subjects were not insured in t, to see whether the gambler's fallacy depended on whether consumers held their ticket or insured it. Analyses of the two kinds of tables yielded very similar results.

16. In experiment 7c, the cell sizes were larger because $r = .5$, so there were enough losses. For the seven consumers in experiment 7c whose data yielded meaningful tests, chi-squared statistics ranged from .05 to 2.38. None were significant at the 10% level in either direction, and the sum of statistics, 6.76, is close to the value expected under independence.

17. For instance, suppose that after a long streak without a loss, prices will rise because of a gambler's fallacy belief that losses are more likely to occur. The rise in prices eliminates the incentive to insure and causes the quantity of insurance bought to be independent of past losses.

18. We shall ignore the income frame model of prospect theory because the amount of trading observed in our experiments casts doubt on it.

19. That is, 61.3% of the tickets were insured in firm-ambiguity periods of experiments 9c–12c, and 48.1% of the tickets were insured in no-ambiguity periods of those same experiments.

20. Another way for the firms to do their mental accounting is to integrate the outcomes P_f and $-L$, so that selling insurance is a prospect with a weighted value of $\pi(r)v(-L + I) + \pi(1 - r)v(I)$ (Thaler, 1985). Assuming that firms integrate P and $-L$ only strengthens the conclusion that no trades take place. We can see this by comparing the results from integrating and separating: 1) If firms integrate, selling insurance has a weighted value of $\pi(r)v(-L + P_i) + \pi(1 - r)v(P_i)$; 2) Segregating earns $v(P_s) + \pi(r)v(-L)$. Since $1 - r$ will generally be a large probability (from .5 to .99 in our experiments), $\pi(1 - r)$ will underweight $1 - r$. Furthermore, $v(-L + P_i)$ is not much better than $v(-L)$, by the convexity of $v(x)$ for losses. By comparing the two weighted values, one can see that the underweighting of $1 - r$ and the closeness of $v(-L + P_i)$ to $v(-L)$ imply that $P_i > P_s$. That is, firms that integrate gains and losses will charge larger insurance premiums than firms who segregate gains and losses. This simply bolsters the conclusion in the text, that firms will charge higher prices than consumers will be willing to pay.

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