

MEMORANDUM

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**RISK-AVERSION IN
INCENTIVE CONTRACTING:
AN EXPERIMENT**

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PREFACE

This Memorandum describes an experimental measurement of risk-taking behavior in a design which approximates certain features of incentive contracts. It was undertaken as a preliminary exploration of the effect of risk on competitive bids and is primarily in the realm of basic research. Practical relevance is limited to suggestions for research in a more realistic environment.

SUMMARY

Incentive contracts allow industry to share the profits or losses caused by differences between the bid and actual cost. This motivates managers to seek efficient operations. But at the time the bid is prepared there may be considerable uncertainty about what actual cost will finally be realized. Thus, even if we allow for managerial efficiency, incentive contracts pose risks not typically present in cost-plus contracts. Very little is known about the effect this additional uncertainty has on bidding behavior. Since industry may lose through a reasonable but too low initial estimate of cost, contractors may bid higher in incentive contracts to hedge against this risk.

The experiment described here examines the effect of varying the sharing rate in a very simplified incentive contract bidding situation. Subjects were asked to compete for contracts with the bidder's sharing rate varying from .10 to .50. They believed that they were competing against two other subjects and that each contract was awarded to the low bidder. The actual cost was determined randomly from a cost distribution known to the subject. The competitors' bids were made available along with the costs of those contracts won.

Actually, each subject competed against synthetic competitors whose bids were random deviates added to, or subtracted from, the subject's own bids. This modification, unknown to the subjects, made the competitive environment identical for each subject. The probability of winning each contract was one-third regardless of the bid. All subjects received identical stimuli in terms of their "competitors'" deviation from their own bids, contracts won, and the actual cost of performing the contract. Sixteen undergraduates participated as subjects, and the results showed that both the average bids and expected profit increased monotonically with sharing rate. It is concluded that in this type of experiment, subjects bid so as to increase their expected profits as a function of increasing uncertainty of the outcome. These findings are in general agreement with the literature on risk-taking behavior.

These results and the increasing significance of incentive contracts suggest that further study of the relation between bidding behavior and risk is warranted. An experiment with actual procurements is suggested as a means of conducting this investigation.

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I. INTRODUCTION

This experiment attempts to simulate certain features of bidding behavior on incentive contracts. In this type of contract, the bidder's profit or loss is determined by a fixed percentage of the bid, plus or minus a given proportion of the difference between the bid and the actual cost. This proportion is the sharing, or incentive rate, and typically varies from 5 to 40 per cent on government contracts of this type. In recent years there has been a rapid shift from cost-plus-fixed-fee contracts (CPFF) to incentive types, and the latter now account for over 80 per cent of defense contracts.

One of the main purposes of incentive contracts, as the name implies, is to encourage efficient operation by permitting the contractor to share in the savings resulting when the actual cost is less than that bid (cost underrun). In the event that actual cost exceeds the bid (cost overrun), the contractor incurs a loss determined by a similar sharing of the overrun. While this is undoubtedly an effective method of motivating management, very little attention has been given to the risk aspect of incentive contracts. Particularly in the research and development area, the bidder assumes a substantial risk over that of a simple CPFF contract, and the contractor may hedge against this uncertainty by increasing the bid level.

This Memorandum describes an experiment designed to examine bidding behavior under several sharing rates or risk levels. The primary purpose is to provide a measure of risk-taking behavior in a setting more closely related to incentive contracts than has been reported for previous experiments of this type. There is no attempt to simulate the managerial efficiency aspects or many of the other complex features of actual incentive contracts. It should therefore be viewed primarily as basic research on risk-taking behavior, and its practical relevance is limited to suggestions for research in a more realistic environment.

* Statement of Secretary of Defense, Robert S. McNamara, before the Subcommittee on Defense Procurement of the Joint Economic Committee, U. S. Congress, April 16, 1964.

II. METHOD

THE EXPERIMENT

In this experiment each subject acted as manager of a medium-sized company. He competed with two other firms for a series of Research and Development incentive contracts containing various sharing rates (r). For the contracts on which his bid (B) was low, he was given the actual cost (C) of carrying out the work. The cost varied and was determined by a random draw from a distribution known to the subject. He learned of his competitors' bid regardless of the outcome.

Two versions of the experiment were run; they will be referred to as Conditions I and II. In the first, the outcome (P) for contracts won was determined by:

$$P = .05B + r(B-C) \quad \text{I}$$

In the second, the formula was:

$$P = r(B-C) \quad \text{II}$$

SUBJECTS

Sixteen male undergraduates from Santa Monica City College participated as subjects -- ten in the first version and six in the second. They responded to a request for subjects to be paid \$1.75 per hour. The age range was 17 to 23, with a mean of 19.4.

PROCEDURE

The subjects were placed in separate rooms and given both written and oral descriptions of the experiment and procedures.* Each subject was assigned an industry and company designation. He was told he was bidding for contracts against the other two companies within his

*The written instructions are presented in the Appendix.

industry, but that, in addition, he was competing for a prize against those companies in the other industries that have the corresponding company identification.

		Industry		
		1.	2.	3.
Company	1.	A	D	G
	2.	B	E	H
	3.	C	F	I

Thus subject A was told he would compete against B and C for contracts and against D and G for the prize. This arrangement was intended to introduce the profit motive, and at the same time convey the fact that intense competition for contracts is not necessarily compatible with long-run profit maximization. Three prizes of five dollars each were awarded under each Condition to the subjects who had accumulated the largest profit at the end of the experiment.

The experiment consisted of 22 rounds of bidding. In each one, five contracts were presented with respective sharing rates of .10, .20, .30, .40, and .50.* The subject was then asked to bid on each contract in the group. He was told that the actual cost of a given contract was to be determined by a throw of a pair of dice according to the following probability distribution:

Dice Value	2	3	4	5	6	7	8	9	10	11	12
Probability	1/36	2/36	3/36	4/36	5/36	6/36	5/36	4/36	3/36	2/36	1/36
Actual Cost (\$ 000)	500	600	700	800	900	1000	1100	1200	1300	1500	1800

* Ideally, we would have preferred to present the contracts randomly in terms of sharing rate; however, this would have interfered with the subject's ability to follow his competitors' actions.

and that the approximate average cost for each contract was one million dollars. He was informed he would win those contracts for which his bid was lowest, except that the customer reserved the right to withdraw contracts if all bids were considered excessive. Ties were to be broken by the toss of a coin. He was given examples of the method of computing the outcome, as well as graphs for determining profit or loss as a function of bid, cost and sharing rate.

In actual fact, the subjects did not compete against other subjects, but against synthetic competitors whose bids were random deviates added to, or subtracted from, the subject's own bids.*

The probability of winning each contract was one-third regardless of the bid. The differences between the subject's bid and his "competitor's" were identical for all subjects in both Conditions, and the same contracts were won by each. Moreover, all faced the same actual cost. Thus, all subjects received identical stimuli in terms of their "competitor's" deviation from their own bid, contracts won, and the

* A random process generated the synthetic competitive bids. Specifically, each competitive bid was set equal to the subject's bid plus a random deviation, δ , generated from a random number, χ , uniformly distributed on the interval, (0,1), by the following rule:

$$\delta = a/b\chi^c,$$

$$\text{where } c = \frac{N \ln a/b}{\ln W}$$

It is easily shown that if a is less than b , the maximum deviation is a , the minimum deviation is $a-b$, and the probability that each of N competing deviations is positive is W . Thus, the minimum and maximum deviations and the player's average win frequency are controlled by this rule.

For greater realism the competitive bid deviations on various sharing rules were correlated in each round by the rule:

$$\bar{\delta}_1 = \delta_1,$$

$$\bar{\delta}_i = \theta \delta_i + (1 - \theta) \bar{\delta}_{i-1} \quad i=2, \dots, M;$$

and the correlated deviations, $\bar{\delta}$, were used in place of the uncorrelated deviations.

actual cost of performing the contract. The profit or loss, of course, depended on the subject's bid.

Approximately five minutes after the bids on each set of five contracts were received, the subjects were told whether or not they had won any contracts. They were given the costs of those contracts won, together with the resulting profit or loss. They were also informed of their "competitor's" bids on all contracts. They were allowed to keep this information in front of them throughout the experiment. After each three rounds of bidding, the variance of the deviation distribution was decreased to simulate the closer competition occurring as a result of knowledge of the competing bids. None of the subjects evinced suspicion that the competitors were not genuine.

III. RESULTS

Tables 1 and 2 present the mean bids for each subject by sharing rate. In Condition I, the outcome for bids won was based on a fixed percentage of the bid, plus or minus the subject's share of the difference between the bid and cost. Condition II was identical to Condition I, except that the fixed per cent of the bid was eliminated.

For Condition I, the over-all mean bids for the ten subjects increase monotonically with sharing rate. Thus the bids increase as a function of the amount of risk the subjects assume. The mean bids for the individual subject generally demonstrate the same pattern, although there are occasional reversals. The expected profit* of the mean bids for the ten subjects also increases monotonically with the sharing rate. However, the extent to which the mean bids exceed the zero-expected-profit bid does not show a consistent relation to the sharing rate. One rather unexpected finding was the number of negative-expected-profit bids. For instance, the mean bids for the subject number 10 had a negative expectation for four of the five sharing rates, and 62 of his 110 bids fell into this category. Of the total of 1100 bids, 275 had negative expected profits, and only one subject consistently followed a strategy of bidding above the zero expectation. Two of the ten subjects showed a net loss for the total experiment.

Figure 1 shows the mean bid by round and sharing rate for Condition I. The pattern of increasing bid levels as a function of sharing rate was generally maintained throughout the 22 rounds. It can be seen that the subjects steadily lowered their bids in an effort to win contracts until round 16, when the losses (incurred as a result of low bids) caused an upturn in the bid level.

*The expected profit, E, or expected value, of a bid in Condition I is:

$$E = .05(B) + -(B-1000).$$

The actual mean of the cost distribution is 1014(000); however, since the players were given 1000(000) as the approximate mean, this value was used to compute expected profits of bids.

Table 1
 AVERAGE BID (000) BY SUBJECT AND SHARING RATE (22 ROUNDS): CONDITION I

Subject	Sharing Rate					Ali Bids	Mean Profit/ Contract Won	No. of Neg.- E Bids
	.10	.20	.30	.40	.50			
1	752	824	876	895	942	858	-21	59
2	819	865	853	948	1045	906	20	16
3	870	1006	1021	1070	986	990	44	14
4	950	874	960	957	1026	954	17	29
5	1000	1218	1232	1279	1250	1196	120	20
6	732	831	888	945	1000	889	17	11
7	1200	1541	1333	1345	1390	1362	170	0
8	577	756	891	1027	1202	891	6	57
9	835	868	942	1043	1120	962	38	7
10	742	706	782	782	876	778	-26	62
(A) Average bid: 10 subjects	853	949	978	1029	1084	978	39	
Expected Profit (E)	28.0	37.2	42.3	63.0	96.2			
(B) Zero-expected-profit bid	667	800	857	889	909			
(A) - (B)	186	149	121	140	175			
No. of Neg.-E Bids	30	52	79	50	64			275

Table 2
 AVERAGE BID (000) BY SUBJECT AND SHARING RATE (22 ROUNDS): CONDITION II

Subject	Sharing Rate					All Bids	Mean Profit/ Contract Won	No. of Neg.- E Bids
	.10	.20	.30	.40	.50			
11	1011	1024	1016	1032	1037	1024	0	62
12	748	798	800	806	813	793	-61	108
13	1260	1128	1135	1145	1137	1161	28	5
14	1185	1222	1270	1294	1304	1255	70	0
15	1031	1043	1065	1097	1125	1072	22	10
16	945	1017	1089	1078	1108	1048	12	38
(A) Average bid: 6 subjects	1030	1039	1062	1075	1087	1059	12	
Expected Profit (E)	3.0	7.8	18.6	30.0	43.5			
Zero-expected-profit bid	1000	1000	1000	1000	1000			
(A) - (B)	30	39	62	75	87			
No. of Neg.-E Bids	55	48	41	38	41			223

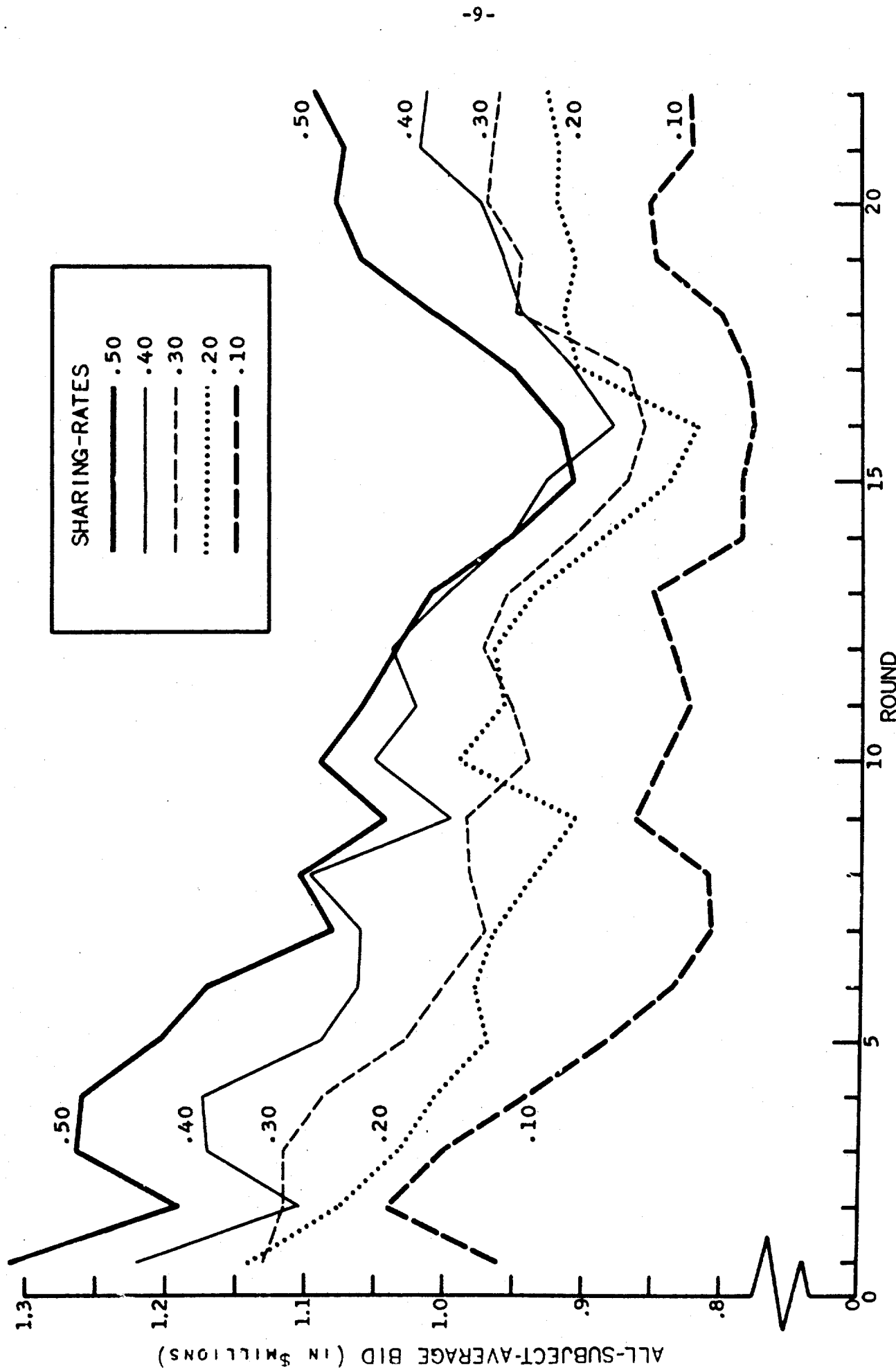


FIG. 1 - AVERAGE BID (10 SUBJECTS) BY ROUND AND SHARING RATE: CONDITION I

The results of Condition II parallel those of Condition I. The over-all mean bid level increases monotonically with sharing rate, as does the expected profit of the bids. However, the differences in bid levels as a function of sharing rate are not as large as in Condition I, and there are some reversals in the pattern for the individual subjects. Any bid below 1000(000) had a negative expectation, and 223 of the total of 660 fell into this category. One subject (12) accounted for 108 of these, but even so, 21 per cent of the bids for the remaining five subjects had a negative expected value.

Figure 2 shows the mean bid by round and sharing rate for Condition II. Attempts to win contracts again drove the average bid to near or below the zero-expected-value level at round 16. The pattern of increasing bid levels as a function of sharing rate is not as consistent for the individual rounds as it was in Condition I.

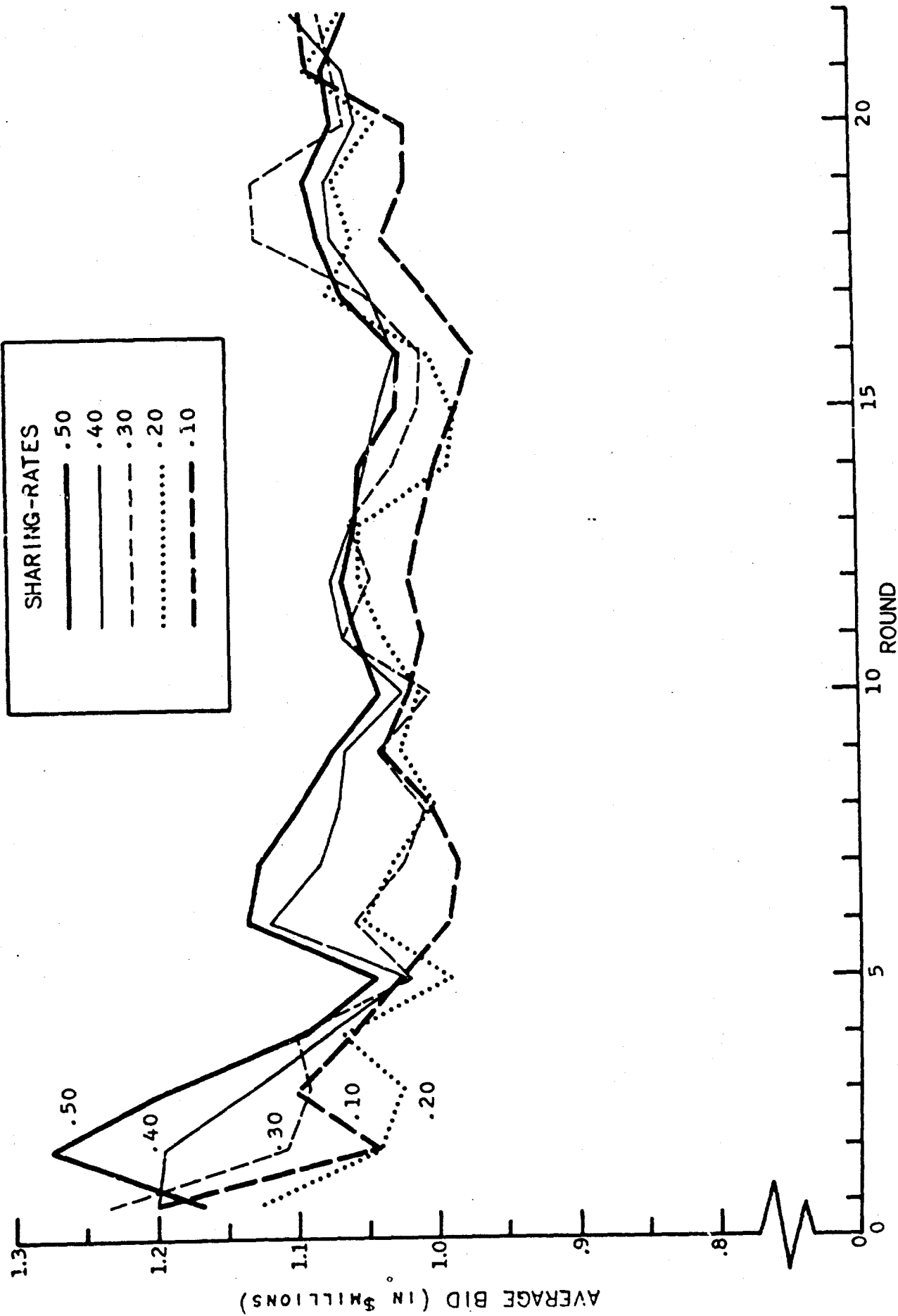


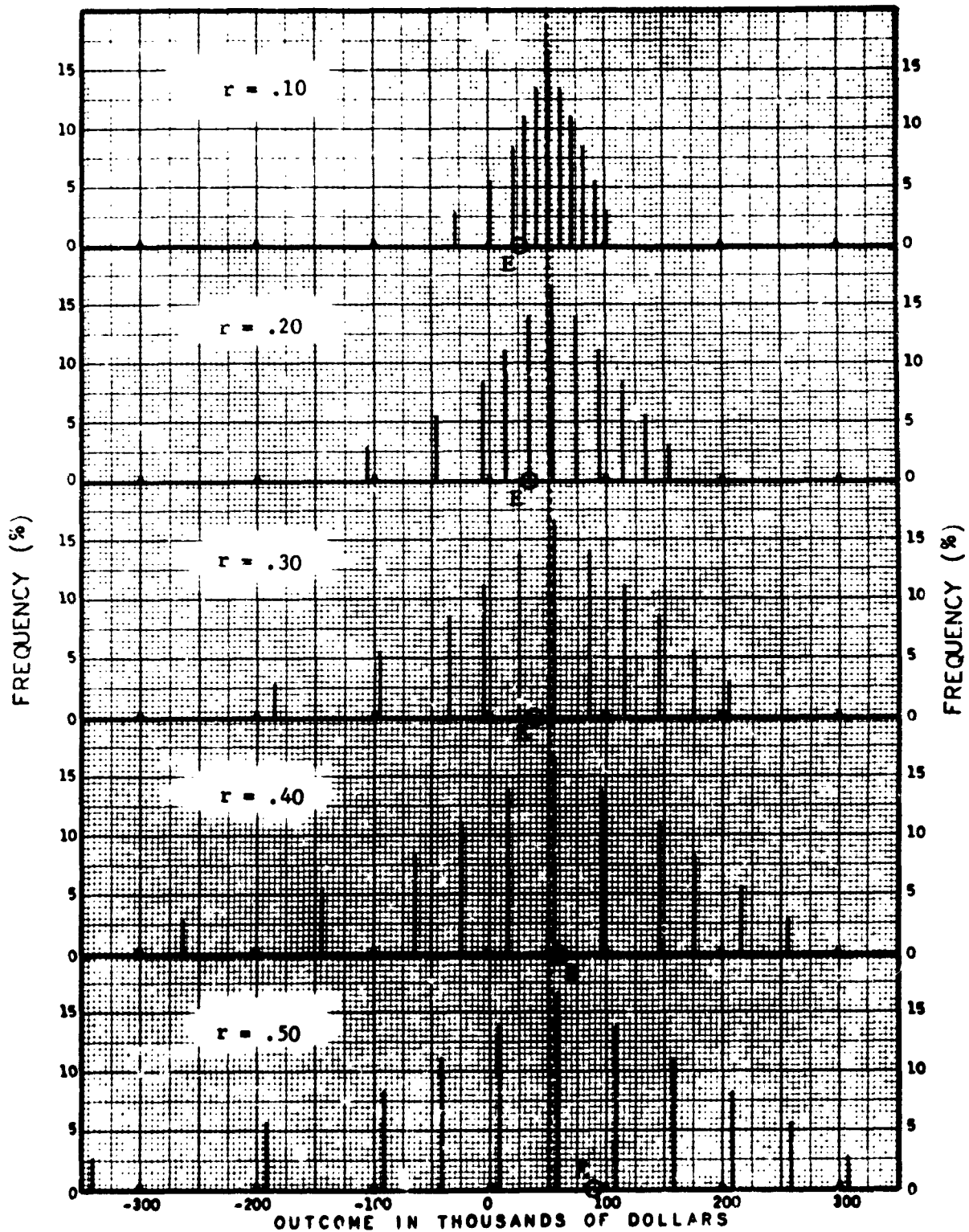
FIG. 2 - AVERAGE BID (6 SUBJECTS) BY ROUND AND SHARING RATE: CONDITION II

IV. DISCUSSION

Condition I differs from most experiments in risk-taking behavior in that subjects compete for the opportunity to take the risk, rather than exercise a preference between alternative wagers. A rational strategy would require that all bids be above the zero-expected-profit level, since bids below this level are inconsistent with the goal of winning the five dollars. It would also be in the subject's interest to cooperate with his "competitors" in not forcing the winning bid level too low, since the competitors for the prize were different from those he "competed" with for the contract. The results, however, indicate that the subjects regularly decreased their bids through the first 15 rounds (Figs. 1 and 2) in an effort to win more contracts, and also frequently submitted bids for which the expected profit was negative. This would seem to indicate that the subjects attach positive utility to winning the contract, even though the resulting behavior may be incompatible with winning the prize.

Condition I also differs from the usual risk-taking experiment in that the outcome is determined by a combination of riskless and risky events. For the low sharing rates, the assured 5 per cent profit (.05B) is relatively large compared to the gain or loss resulting from the risky portion of the outcome-- $r(B-C)$. Both the results and the subjects' comments indicate they are willing to bid lower and accept lower expected profits for contracts involving the smaller risks.* Figure 3 shows the relationship between expected profit and variability of outcome. The theoretical frequency distribution of outcomes for a bid of 1014(000) (the true mean of the cost distribution) is shown for each sharing rate. If the subject makes this bid, his

*In some exploratory trials prior to the experiment, a contract whose outcome was simply .05B was included, i.e., $r = 0$. The bids on this contract were clearly discontinuous with the remainder -- the participants being willing to make extremely low bids to win a contract involving no possibility of loss. Apparently a certain profit is perceived quite differently from one involving even a small amount of uncertainty.



... EXPECTED PROFIT, $B = 1014$

E ⊙ EXPECTED PROFIT FOR AVERAGE BID, CONDITION I

FIG. 3 - THEORETICAL FREQUENCY DISTRIBUTION OF OUTCOMES FOR A BID OF 1014(000) BY SHARING RATE (r): CONDITION I

expected profit will be $.05 \times 1014 = 50.7$ for all contracts; however, the variability about this average increases markedly as a function of the sharing rate. As seen in Fig. 3, the subjects are willing to accept average expected profits, E , of less than 50.7 for the low-variability contracts, but demand higher expectations for those with high variability.

A difficulty in interpreting these results is the fact that, although the mean bid level and expected profit increase monotonically as a function of sharing rate in Condition I, the difference between the mean bid and the zero-expected-profit level does not evidence a similar relationship (Table 1). It is possible that the subjects made their bids with reference to the zero-expected-profit level, and the increase of bid level and expected profit with sharing rate is simply an artifact of this strategy.

Condition II, where the zero-expected-profit level is constant for all sharing rates, was conducted in an effort to clarify this problem. Again, it was found that the mean bid level and the accompanying expected profit increase monotonically with sharing rate. It is concluded that, in the type of experiment described here, subjects make higher bids, with accompanying increase in expected profits, in response to increasing uncertainty or variance of the outcome.

Repetition of the experiment under Condition II also permitted further examination of the tendency to submit negative-expected-profit bids observed in Condition I. There was interest in learning whether bids with negative-expected-profit were frequently submitted because of a willingness to accept such unfavorable risks in order to win the contract from the competing subjects, or whether such bids were made inadvertently without realization of their consequences. The zero-expected-profit level could be readily determined from the graphs given the subjects; however, the graphs differed for each sharing rate, and the subject might have made such bids unintentionally if he did not regularly refer to the appropriate graph. In Condition II, the zero-expected-value level was 1000(000) for all sharing rates, and it was quite clear to the subjects that any bid below this was less than the average cost of the contract, and thus would result in an

unfavorable risk. The results (Table 2) show that the subjects still submitted a large number of bids below this level. Further examination, however, shows that only one subject (12) acted in a particularly irrational manner and completed the experiment with a net loss. Subject 11 made 62 bids below 1000(000) out of a total of 110, but only 4 of these were below 950(000). Subject 3 made 38 bids below 1000(000), but 63 per cent of these were for the .10 and .20 sharing rates, where the consequences were not especially severe. Subject 14 made no bids below 1000(000); subject 15 made none after the third round; and subject 13 made none after the eighth round.

The results of this experiment, showing increasing bids and expected profits as a function of risk level, are in general agreement with the literature on risk-taking behavior. Lichtenstein performed a comparable experiment and found subjects preferred low to high variance bets when the expected value was held constant.⁽¹⁾ Suydam and Myers found that when subjects were offered a choice between a small, but certain profit, and draws from various symmetrical, rectangular distributions of gains and losses ($E=0$), the preference for the latter decreased as the range of the risk increased.⁽²⁾

This is not to say that subjects necessarily choose so as to minimize the variance of the outcome of the risk-taking event. Where the level of risk (size of wager) is fixed, subjects frequently prefer low probability-high payoff wagers to those with high probability and low payoff. For instance, horse-race bettors accept considerably lower expected values for long-shots than for short-odds horses (favorites), and thus increase the variance of their outcome at the expense of maximizing expectation.⁽³⁾ However, when the amount that may be lost is not fixed, as in this experiment, behavior is generally consistent with a hypothesis that the utility of risk is negative at all levels and is negatively accelerating as a function of the size of the possible loss.⁽⁴⁾ In this regard, Lichtenstein found that when subjects were asked to choose between sets of three bets, where the sets had equal expected value and variance, they showed a definite aversion to sets containing a low probability-high loss wager.⁽¹⁾

Turning now to actual experience with incentive contracts, there is very little specific information on how the risk-taking aspect influences management bidding decisions. Moore argues that the tendency to avoid risk is quite strong in industry and that an alternative with a low profit yield will often be preferable to one that has a higher expected profit but is less safe.⁽⁵⁾ Similarly, Scherer reports:

Our case studies provided several clear examples of contractor willingness to accept lower average profit expectations to avoid risk when substantial cost uncertainties were present.... Company representatives explained that they would gladly accept lower CPEF profit rates in exchange for the certainty that cost overruns would be fully reimbursed if they should occur.⁽⁶⁾

Scherer found that companies frequently negotiated for low sharing rates on incentive contracts, and this was true even though the companies were large enough to absorb the possible losses with relative impunity. "The main basis of the observed risk ~~conversion~~^{aversion} behavior appeared to be an assumption that short-run losses were a symptom of managerial failure and therefore would be followed by possibly drastic organizational changes."⁽⁷⁾ Grayson studied decisions in oil and gas drilling operations and found that, while companies required higher expected returns for high-risk endeavors, they differed considerably in their willingness to accept such risks, as opposed to sharing the uncertainty with other investors.⁽⁸⁾

The experiment described in this Memorandum is certainly far removed from the complex incentive contracts currently being employed between government and industry, and no claims are made about direct relevance of the results in this regard. There are complicated renegotiation clauses in actual incentive contracts, not to mention the difference between experimental subjects and management personnel. However, the results of this and related experiments on risk-taking behavior do raise an interesting question. If we accept the intuitively ~~reasonable~~^{reasonable} hypothesis that individuals (and companies) are basically risk-averse, and require higher expected profits as a function of increasing uncertainty of outcome, then clearly this may ~~effect~~^{effect} some, or all, of the savings resulting from the increased managerial efficiency

attributed to incentive contracts. It also seems reasonable that such a relationship between expected profit and risk would be at least linear, and perhaps positively accelerating as a function of increasing risk (as found in the present experiment). On the other hand, while there is no experimental evidence, it is not clear that managerial efficiency would increase linearly as a function of sharing rate. It appears more likely that the results of cost-reducing efforts would be a negatively accelerating function of sharing rate. In other words, if entrepreneurial effort could be measured, it seems doubtful that raising the sharing rate from 20 to 40 per cent would result in twice the increased efficiency over that for a straight CPFF contract. This would suggest that, while a relatively low sharing rate might result in savings over a CPFF contract, a high rate might result in a higher cost to the buyer.

These suggestions are strictly speculative, but the marked shift from CPFF to incentive contracts in recent years seems to warrant further study of the effect of risk on actual bidding behavior (or target cost), and some attempt to determine optimal sharing rates for various situations. One approach would be to develop more realistic measures of the cost of risk-taking through "live" experiments in which companies submit separate bids on special contracts for a relatively high and low sharing rate.

APPENDIX

Following are the two items which, along with oral instructions, were given to each subject at the beginning of the experiment. The instructions and the graph shown here were those used for Condition I. Those used for Condition II were modified to conform with the change in the payoff rule.

COMPETITIVE BIDDING EXPERIMENT

This is an economic experiment whose purpose is to study competitive bidding on Research and Development contracts. You are to act as manager of a medium-sized electronics company and will be asked to submit bids on each of a number of research and development contracts. These will be presented in groups of five.

You will be competing with two other firms. Your identity in this experiment will never be disclosed, nor the identities of the other two competing managers. After your bids are submitted on the five contracts, they will be compared individually with the bids of each of your competitors, and awarded to the low bidder. Tie bids will be broken by a coin toss. The customer reserves the right to withdraw contracts for which all bids are considered excessive. All three bids on each contract will be made known to each of the three bidders.

You will be told the actual cost of those contracts you win. This will be determined by a throw of a pair of dice as follows:

Dice Value	2	3	4	5	6	7	8	9	10	11	12
Probability	1/36	2/36	3/36	4/36	5/36	6/36	5/36	4/36	3/36	2/36	1/36
Actual Cost (\$ 000)	500	600	700	800	900	1000	1100	1200	1300	1500	1800

The profit or loss on each contract that you are awarded will be determined by a basic profit rate of 5 per cent of the bid cost plus or minus a given fraction of the difference between bid and actual cost.

This fraction (incentive rate) will vary, each contract having one of five values; 0, 10, 20, 30, or 40 per cent. This determines the extent you share in the profit or loss resulting from the difference between the bid and actual cost. The following table provides examples of the profit or loss as a function of actual cost for a bid of \$1,100 (in thousands) at three sharing rates. The basic 5 per cent profit on this contract is \$55(000).

Actual Cost	Bid-Cost	Sharing Rate		
		0 per cent	20 per cent	40 per cent
500	+600	$55 + 0 \times 600 = 55$	$55 + .2 \times 600 = 175$	$55 + .4 \times 600 = 295$
700		400 55	400 135	400 215
900		200 55	200 95	200 135
1100		000 55	000 55	000 55
1300		-200 55	-200 15	-200 -25
1800		-700 55	-700 -85	-700 -225

Through effective play it should be possible for you to obtain a sizeable profit for your company.

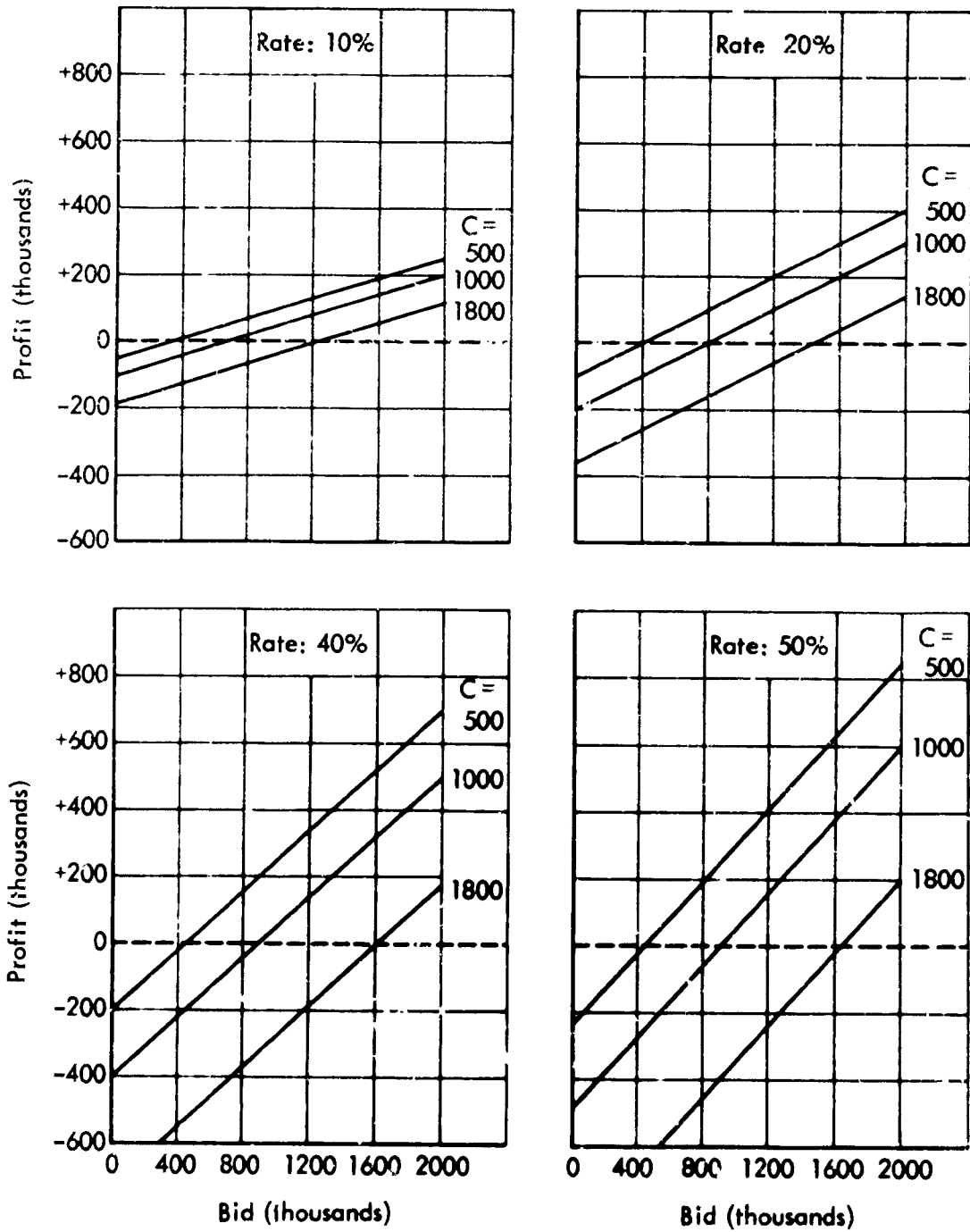


Fig. 4 - PROFIT OR LOSS AS A FUNCTION OF BID LEVEL, COST AND SHARING RATE:
CONDITION I

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