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APPLICATION OF UTILITY THEORY TO

DRILLING INVESTMENT DECISIONS

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INTRODUCTION

The continued existence and growth of a corporate firm in our present-day competitive economy depends to a great extent on having competent decision makers. These persons shape the daily and long range policies of the firm by their choices of particular investments. Many of these decisions are made under conditions of risk or uncertainty; that is, where one of several outcomes will result from choice of a given decision alternative. Much has been written concerning the decision maker's function, particularly under conditions of uncertainty. However the very existence of uncertainty and the complexities of relating numerous relevant factors into an optimal decision strategy combine to make the task of decision making quite difficult.

One such example of uncertainty is the type of decisions involved in the dedication of large amounts of capital for the drilling of oil and gas wells by the petroleum industry. The oil company decision maker must consider at least two factors: the degree to which the outcomes such as a producer or dry hole are deemed probable, and the degree to which the possible outcomes are desired relative to one another. The second factor can be broadly defined as the "value phase" of the decision, and usually consists of associating some measure of value to each possible outcome. The decision maker must then determine how these measures of value relate to the current goals and policies of the firm. This research will attempt to show that mathematical utility theory appears to be a better value criterion for drilling investment decisions than those now in use because it systematically accounts for certain emotional biases that each decision maker has. These biases include his (or the firm's) corporate goals, his asset position, and his preferences for taking gambles or risks.

While a detailed study of oil and gas well drilling investment decisions is admittedly focusing on only a small, specialized group of decision makers in our overall economy, a few statistics will indicate the significance of these decisions. During 1965 the domestic petroleum industry drilled over 41,400 wells in the United States to an average depth of 4380 feet per well (1). At an average cost of $15 per foot, this represents an expenditure of $2,720,000,000. Considering that there will be 15 companies involved (through joint interest operations) in every 10 wells drilled, and assuming additional prospects representing 20 per cent of the total wells drilled were rejected for one reason or another, there were at least 70,000 individual drilling investment proposals evaluated by these decision makers during 1965! These figures represent only the actions of domestic firms for drilling within the United States. The similar type decisions made by petroleum companies engaged in competitive development of other oil and gas provinces throughout the free world would increase these figures considerably.

The general format of this thesis consists of four parts. The first part is a description of the groups of people making these decisions, together with a discussion of the methods and measures of value that are currently used in drilling investment decisions. The second part presents the historical formulation of utility theory and briefly describes the current "state-of-the-art" when using it in executive decisions. It will be shown that the problem of how to initially construct a functional representation (utility curve) of a decision maker's risk preferences has been the principle obstacle to its implementation. The third portion describes a drilling investment decision test that was developed in this research project to yield data for the calculation of such utility curves. To determine the usefulness of this test it was presented to a number of decision makers in various oil companies. The results of these decision experiments are included in the third chapter. The concluding chapter illustrates the practical use of utility theory for drilling investment decisions. Implications of the research and conclusions are also presented at that point.

Although this thesis is concerned with only one small segment of corporate operations, the conclusions and implications contained herein are considered applicable to the total area of corporate decision policies.

CHAPTER I

PRESENT METHODS USED IN DRILLING INVESTMENT DECISIONS

This chapter is a general over-view of the drilling investment decision as it is now practiced. The first section presents a description of the drilling decision making personnel and procedures. The second section discusses some of the many factors which are considered in a drilling investment proposal, and the final section summarizes the general economic criteria, or measures of value now used to evaluate the proposal. This latter section points out critical weaknesses of the present methods and suggests the application of utility theory as a superior decision criterion.

Description of Decision Making Group

The corporate structure of most domestic petroleum companies includes a group of executives who are vested with authority to allocate funds for the drilling of exploratory and development wells. This group reviews each drilling prospect and either authorizes or rejects the proposal according to its individual merits. This body typically consists of the top executive of the particular management echelon together with his subordinate department heads. The size of the group varies from 6 to 10 people in the larger organizations to perhaps 2 or 3 in the smaller firms. The decision group may also include the heads of certain staff groups, such as engineering, geological, and land departments. Schematically, a typical decision group would appear as in Figure 1. These groups may convene daily, bi-weekly, or once a week depending on the quantity of drilling prospects being considered. In a few organizations the drilling investment proposals are presented to each decision maker individually rather than to the assembled group.

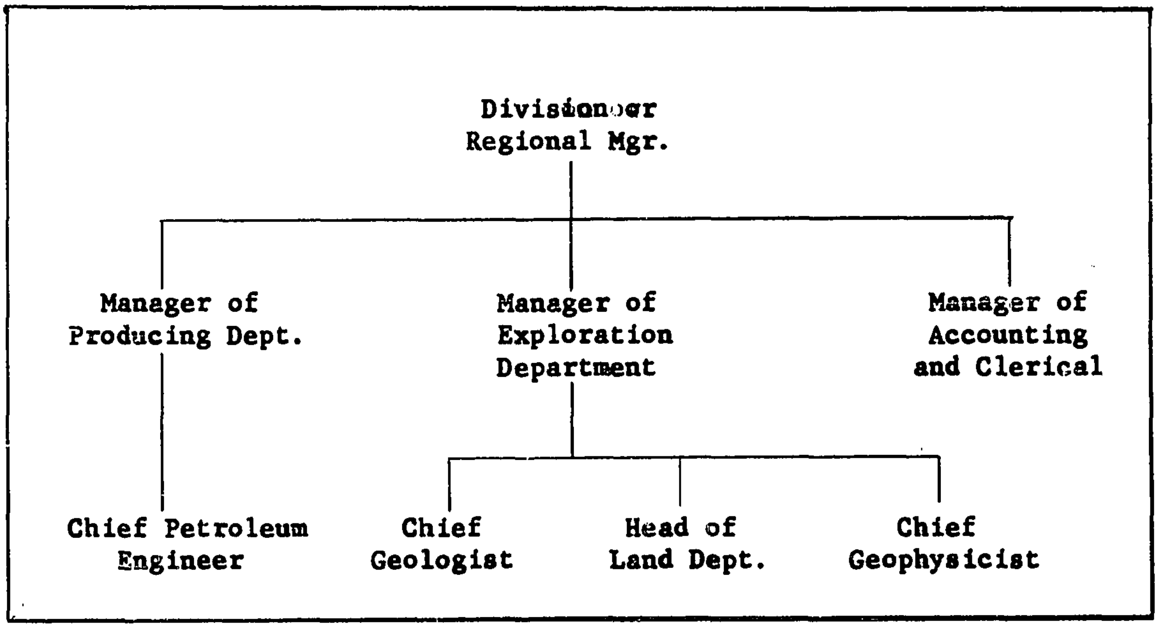


FIGURE 1. -- Typical drilling investment decision making group

A drilling investment proposal is usually presented to the decision group by a person who is not a member of the group, such as the petroleum engineer or geologist that prepared the recommendation. This person will present a concise summary of the pertinent engineering and geological factors, together with the economic measures of value utilized by the company to rate drilling investments. The group may then discuss the proposal or clarify certain points, after which a decision to accept or reject is made. The manner in which the group members make the decision probably varies from proposal to proposal and undoubtedly varies between companies. For example, one decision group may vote, another group may state their individual thoughts after which the top executive makes the decision personally.

The above description of the decision making groups is considered typical of most oil company organizations. Specific descriptions of the decision groups which participated in the experimental phase of this research will be given at a later point. It is to be observed that these decision making groups are usually responsible for additional types of decisions within the corporate echelon, such as acreage purchases, plant and facility expenditures, etc. However, drilling decisions generally constitute a primary function, and are the only types of decisions being considered in this study.

Description of Factors Considered in Drilling Decisions

A drilling investment proposal is usually presented as a brief summary of the pertinent considerations. A list of some of these factors might be subdivided into tangible (measurable, or definitive) and intangible factors (Table 1). While this list is perhaps not exhaustive it contains the essential factors considered in the decision to drill a well. Grayson presents a lucid description of many of these factors, particularly those designated in Table 1 as tangible (2). Although the decision problem will be redefined shortly, this list is presented to illustrate the multitude of factors which are normally considered. It is to be noted that many of these factors are not contained quantitatively in the usual profitability measures. Hence, a decision may

TABLE 1

FACTORS WHICH ARE CONSIDERED IN DRILLING INVESTMENT DECISIONS

TANGIBLE FACTORS

1. Geologic Conditions: structural position, closure, trends, availability of seismic data, etc.

2. Engineering Considerations: performance of offset or nearby wells, why were nearby dry holes abandoned, what are estimated reserves, what is probability that recoverable reserves will equal those originally estimated (statements of risk).

3. Drilling Commitments: lease-expirations, royalty owner demands, offset obligations, forced pooling, penalty clauses, etc.

4. Availability of Funds.

5. Profitability: length of time to payout, return on investment, allowable production, what will be effects on competitive position if well not drilled, if a gas well how long will it be shut-in.

6. Weather Conditions: applicable for drilling operations in certain parts of the world.

INTANGIBLE FACTORS

7. Decision maker's Characteristics: experience, judgment, personal bias, opinions, mood, intuition, gambling (risk) preferences.

8. Corporate Goals.

9. Political Factors.

10. Luck.

resolve to one of evaluating the "plus" factors against the "negative" factors in some arbitrary and subjective manner. While certain "plus" and "negative" factors involving judgment will always appear in drilling decisions, it is desirable to combine some of the considerations which occur in every decision (such as asset position, corporate goals, and risk preferences) into a formal decision criterion. This study will show that application of utility theory is a convenient procedure to achieve this goal.

At this point it is well to consider where the uncertainty exists in these factors. The decision to drill a well for oil or gas is a classic example of uncertainty. Obviously when a company is going to invest as much as two million dollars to drill a well it would be highly desirable to be assured, with certainty, that the well will be successful and will encounter reserves at least equal to those estimated at the time of decision. Certainly modern petroleum engineering, geological, and geophysical techniques have improved our ability to predict suitable drilling locations, and thus try to achieve some degree of certainty. The fact remains, however, that the best of our modern techniques still are not totally satisfactory, as evidenced by the fact that of the 41,423 wells drilled in the United States in 1965, 16,016 were dry holes (1). These totals include 8265 exploratory wells of which 7150 were dry, and 33,158 development wells of which 8866 were dry. Therefore, in any drilling investment proposal the decision maker must always acknowledge that one of the possible outcomes will be a dry hole.

Most drilling investment decision makers will also acknowledge that luck is an ever-present factor. In this context, luck might be defined as the fortuitous occurrence of some secondary event which prevents the total loss of the investment when primary objectives do not occur as forecast. For example, a well was recently drilled in the Anadarko Basin of northwest Oklahoma to test Morrow sands. Upon reaching total depth the operator found the Morrow was shaled out, but logs indicated the presence of a stray Red Fork interval. The zone was tested and completed as a fairly good gas well. Since there was no geological evidence of potential Red Fork pay in this geographical area before the well was drilled, certainly the operator must acknowledge the presence of luck in preventing a $200,000 loss in a dry hole. Another example is the discovery of the large Swanson River Field in Alaska. Subsequent development after completion of the discovery well, the Richfield Oil Corporation - Swanson River Unit No. 1, indicated it to be the northernmost productive well in the field! It is interesting to conjecture if the 59 well field would have been discovered if the Swanson River Unit No. 1 had been drilled a mile north of its present location.

A redefinition of the factors in the drilling decision is now appropriate to bring the objectives of this research into sharper focus. Irwin D. J. Bross, in his book Design for Decision, suggested that the decision process basically includes two parts: a predicting system and a value system (3). Following this definition but in the context of the problem at hand, the predicting system represents the assessment of drilling prospects by the geologist and petroleum engineer - roughly, the "tangible factors" in Table 1. The value system consists of associating some measure of value to each possible outcome and evaluating these measures as they relate to the decision maker's goals and desires. For example, a commonly used measure of value is our monetary system. Certainly the drilling prospect of a producer with a net profit of $600,000 or a dry hole costing $200,000 elicit definite reactions in the decision maker's value system. From these reactions he probably is able to reach some sort of decision about the prospect. While the dollar is a remarkably versatile measure of value, utility theory appears to represent a superior value system that not only considers monetary losses and gains, but also the risk preferences, asset position, and goals of the decision maker as well. The remainder of this study will be concerned with the value system of the drilling investment decision maker.

Although no further emphasis will be given the predicting system, which is normally associated with the petroleum engineer's conclusions and recommendations rather than the decision maker, it is well to emphasize the great importance of the probability estimates presented to the decision group. For an optimal decision, a company's management must not only have a sound value system but also a clear assessment of the risk associated with each drilling prospect considered. If the probability estimates are poor, the decision based upon them will also be poor - even though the decision maker might be using the best value criterion available. It will be seen that the application of utility theory involves the probabilities of occurrence of various outcomes by direct multiplication. However, obtaining representative probability estimates for the outcomes which might occur from the drilling of a well is indeed a problem in itself. The emphasis on the value phase of the decision in this study is not meant to imply that risk analysis is any less of a problem. On the contrary, the growing emphasis on formal decision theory will ultimately require similar research to improve our abilities to assess risk in drilling investment decisions.

Drilling Decision Criteria

While most, if not all, of the factors listed in Table 1 are considered in the decision, the final and predominating considerations are usually the profitability criteria. For no matter how impressive the geological support for a proposed location, the decision maker is not going to favor the proposal if it does not stand a reasonable chance of being an economic success. The criteria now being used to evaluate "economic success" usually include serveral, or all, of the following:

1. Payout time
2. Undiscounted or discounted profit to investment ratio (return-on-investment)
3. Discounted rate of return
4. Expected monetary value (mathematical expectation).

In addition, various companies may have other more esoteric criteria which they apply in combination with the above factors. For example, Northern (4) lists several additional measures of value, and Hardin (5) describes a "profit-risk" ratio for evaluating exploratory drilling investments.

The first three measures of value listed above contain no statements of risk. Their use as value criteria in drilling investment decisions requires some statement of minimum acceptable limits. For example, what is the minimum rate of return that should be permitted? Or what minimum return-on-investment should be established for drilling investments? These are sometimes difficult questions to answer. For example, use of the rate of return criterion would suggest that the minimum acceptable rate of return should be the firm's cost of obtaining capital to finance the investment. It is a common practice, however, to arbitrarily select a higher minimum rate of return to account for the uncertainty of reserve estimates, the chance of a dry hole, etc. The decision maker must then ask himself "How much above the cost of capital should I establish the minimum rate of return to insure protection from the chance of a dry hole, but yet be assured of not passing up good prospects because of a minimum rate of return that is set too high?" It is also a common practice, particularly among smaller operators, to use the return-on-investment ratio as the principle measure of value. They may use as a criterion obtaining $0.80 net profit per dollar invested. To select this minimum requires consideration of the firm's short and long term goals and the rate of turnover of invested capital (payout).

In addition to the problem of establishing minimum acceptable values of the first three decision criteria, it is easy to visualize that these "minimums" do not remain constant with time. A raising or lowering of previously set minimums may be required as changes in the firm's asset position and goals occur. This of course introduces the possibility of inconsistent decision policies. A company may, due to lowering of the minimums, drill a prospect that it had rejected a month prior, or vice versa. All of these problems associated with use of the first three measures of value result from a value system that is based solely on monetary values.

The concept of mathematical expectation, or expected monetary value, is the traditional approach to decision making under conditions of uncertainty. Use of this criterion consists of multiplication of a probability of occurrence with the financial payoff for each possible outcome. For example, if P is the probability that a particular outcome will occur and S is the payoff (profit or loss) to be realized by the decision maker if the outcome occurs, then $P \times S$ is the "expected value" of the outcome. If there are two or more possible outcomes the expected values for each outcome are summed algebraically, with the decision being to accept the act if the sum is positive. If several decision alternatives are being considered the criterion is to select the alternative which will maximize expected monetary value.

As an illustration consider the drilling prospect shown in Table 2 in which the decision maker is considering the alternatives of drilling or farm out. Using the criterion of maximizing expected value the decision is to drill the prospect. It can be shown that mathematical expectation is nothing more than an arithmetic average of financial results over repeated decisions. That is, the expected value of $280,000 is the average per-well profit that will be realized if a series of wells having payoffs and probabilities shown in Table 2 are drilled.

Mathematical expectation is a better measure of value than the first three decision criteria listed because it includes statements of risk. The method can be used with any number of possible outcomes (so long as the probabilities for all outcomes stated sum to 1.0) and can include the evaluation of any number of decision alternatives. The notion of expected value is at least three centuries old, although it was given slightly different terminology during its history. Laplace termed the concept "mathematical hope", and in his book <u>A Philosophical Essay on Probabilities</u> (6), published in 1814, he stated: "... we ought always in

TABLE 2

EXAMPLE OF EXPECTED VALUE CONCEPT

Outcomes	Prob. of Outcome	Decision Alternatives	
		Drill (100% WI)	Farm Out (Retain 1/8 ORI)
Dry Hole	0.4	- $200,000	0
Producer (5 BCF)	0.6	+ $600,000	+ $50,000

EXPECTED VALUE OF "DRILL":

$$(-\$200{,}000)(0.4) + (+\$600{,}000)(0.6) = \underline{+\$280{,}000}$$

EXPECTED VALUE OF "FARM OUT"

$$(0)(0.4) + (+\$50{,}000)(0.6) = +\$30{,}000$$

DECISION: DRILL

the conduct of life to make the product of the benefit hoped for, by its probability, at least equal to the similar product relative to loss."

It is significant to note that while expected value is a better decision criterion than those previously listed because it includes statements of risk, it still has a critical weakness. This results from the fact that it implies that the decision maker is totally impartial to money, regardless of the amount involved. If a major oil company were considering the prospect in Table 2 it may well choose to drill.

But a small independent operator with a limited annual drilling budget is going to view the proposal differently. In fact, the specter of possibly losing a sizeable portion of his annual budget in just one dry hole may cause the small operator to reject the proposal, despite its apparent profitability. And yet if both decision makers were using expected value as the decision criterion, the decision for both would be to drill.

Some of these philosophical questions concerning mathematical expectation and personal values were the cause of much concern to some of the early mathematicians. The noted Swiss mathematician Daniel Bernoulli (1700 - 1782) was one of the first to suggest that monetary values alone do not adequately represent a person's value system. He suggested that the utility (desirability, usefulness) of money is inversely proportional to the amount he already has. He proposed this theory to resolve the famous Saint Petersburg Paradox, which is described below as a simple coin-flipping game.

> Player A pays $1 to Player B for the privilege of playing the game. The game continues until the first tail appears. For each head that occurs Player B pays a reward (prize) of $1 to Player A. The decision is: Should Player A play the game?
>
> To evaluate the decision a payoff table is constructed of the possible outcomes of the flip of a fair coin.

Outcome	Probability of Outcome	Reward to Player A, dollars
T	1/2	0
HT	1/4	1
HHT	1/8	2
HHHT	1/16	3
HHHHT	1/32	4
⋮	⋮	⋮

The expectation of Player A, E_A, is then given as

$$E_A = \frac{1}{2}\times 0 + \frac{1}{4}\times 1 + \frac{1}{8}\times 2 + \frac{1}{16}\times 3 + \frac{1}{32}\times 4 + \ldots - 1$$

(where the -1 is the cost of playing the game).
It can be shown that the above series converges to +1 and hence $E_A = +1 - 1 = 0$. This game is called a "fair game" since the expectation of both Players is zero. Player A's winnings, therefore, will exactly equal his losses (cost of playing the game) over a long number of games. Conclusion - in the long run he has nothing to gain by playing.

The rules of the game are now revised slightly to illustrate the Saint Petersburg Paradox.

The rules are exactly as stated previously except for the rewards made by Player B to Player A for the occurrence of a head. Now Player B pays $1 for the first head, $2 for two heads, $4 for three heads, $8 for four heads, etc., each time doubling the previous payment. Naturally Player A should pay a higher stake (than $1) to play since the rewards are higher. The question is: What is a fair stake for Player A to pay for the privilege of playing the game?

Again the expectation of Player A is an infinite series, minus the stake, and is given as

$$E_A = \frac{1}{2}\times 0 + \frac{1}{4}\times 1 + \frac{1}{8}\times 2 + \frac{1}{16}\times 4 + \frac{1}{32}\times 8 + \ldots - STAKE \quad ,$$

$$E_A = 1/4 + 1/4 + 1/4 + 1/4 + 1/4 + \ldots - STAKE.$$

Since the sum of the series is infinite, Player B should refuse to play even though Player A offers a stake equal to all the gold in Fort Knox! This is a paradox because most people would gladly be Player B if Player A offered to pay a stake of one million dollars.

To resolve this Paradox, Daniel Bernoulli suggested that the logarithm of the reward (payoff), rather than the reward itself, is the appropriate measure of the utility of the possible rewards to Player A. This suggestion of course made the series of expected values converge, from which a "fair" stake could be computed. Historically, this is apparently the first suggestion that an individual's value of money is related to how much he already has. Bernoulli thus introduced the notion of utility in this context. It is interesting to note that this ingenious solution to the Saint Petersburg Paradox merely led mathematicians to devise new versions of the game in which the expectation once again becomes infinite, even with logarithms.

All of the discussion above, while pointing out the critical weaknesses of the commonly used measures of value, really suggests that ultimately the decision maker must find a measure of value which accounts for certain emotional biases as well as monetary values. To do this he must examine the extent to which various biases such as asset position, goals, and risk preferences relate to monetary payoffs. An excellent example of how a simple decision can be complicated by a person's feelings was given by Bross (3). His example is given below in a condensed and paraphrased form:

> Suppose Joe Smith is sitting in his easy chair at 6:00 P.M. and is trying to decide how to get to the office tomorrow. After careful consideration he determines he has just two feasible alternatives:
>
> A: Drive his car
>
> B: Take the bus.
>
> To choose one or the other he could flip a coin. But this technique has no assurance to Mr. Smith that the decision will be satisfactory. What then is a satisfactory outcome? He could be primarily concerned with saving money, or perhaps the saving of time is more important.
>
> Suppose he states that his purpose is to be sitting comfortably in his easy chair at 6:00 P.M. tomorrow night. So now to make the decision he must predict the outcomes of each course of action and determine which will best satisfy his purpose. Suppose he predicts that if he drives his car he can be home by 6:00 P.M. sitting in his easy chair, but if he takes the bus he'll still be walking home from the bus stop at 6:00 P.M. His decision is then obvious. But there are other possible outcomes. For example, if he drove his car he might be sitting in a hospital with his leg in a plaster cast at 6:00 P.M. rather than at home. Or perhaps the car might stall on his way home and at 6:00 P.M. he might be walking for help instead.
>
> Moreover, what if he had specified as his desired objective a general feeling of well-being at 6:00 P.M. tomorrow night? Perhaps Joe might be in a much happier frame of mind if he was walking home jingling in his

> pocket the extra money he saved by riding the bus than if he was sitting in his easy chair at 6:00 P.M. figuring out how much it would cost him to fix the dent some one had put in his fender!

Bross suggests that any measure of value or desirability must try to weigh the pleasant outcomes against the unpleasant, and that such a measure must deal with, or take cognizance of many outcomes and cross-purposes.

Chernoff and Moses prepared four hypothetical wagers in their book Elementary Decision Theory (7) which graphically illustrate how factors other than money alone influence one's decisions. These wagers are listed below (slightly paraphrased) as possible alternatives to the question - "Would you accept the following bets?"

A. On a flip of a fair coin you win $2 if a head, and you pay $1 if a tail.

B. Your entire fortune is $10,000,000. On a flip of a fair coin you win $20,000,000 if a head, you lose your fortune if a tail.

C. You intend to spend all your cash on an evening of fun at an amusement park. You have $3. On a flip of a fair coin you get another $3 if a head, you lose your $3 if a tail.

D. You are desperate to see the big college football game. You have $3 but a ticket costs $5. On a flip of a fair coin you win $3 if a head, you lose your $3 if a tail.

Undoubtedly most rational people would accept the first bet since they stand to gain twice as much as they might lose even though the likelihoods of each outcome are equal. The second bet offers exactly the same ratio of payoff to loss and the same probabilities as wager A. However, most people would probably not accept the gamble since they might lose an entire fortune. Wagers C and D are "fair" gambles (the expectation of either bet is zero) and both involve equal dollar amounts. Acceptance of wager C would depend on whether $3 spent for fun would satisfy the decision maker. On the other hand, a rational person would probably accept wager D, since the possibility of losing the wager is no worse than still having his $3 but no football ticket. These wagers illustrate that the value of money to its owner does not always appear proportional to the amount of money involved in the decision. The possibility of having $30,000,000 does not appear to be 3 times as valuable as $10,000,000 to the millionaire, but $6 is many times more valuable than $3 to the football enthusiast.

In this discussion the weaknesses of the measures of value now in use in drilling investment decisions have been defined. In addition some of the factors which bias the decision maker's reactions to monetary payoffs have been described. At this point one may ask "Now that the problem has been stated, what is a better decision criterion?" An approach would be to modify the concept of mathematical expectation so that it accounts for the decision maker's asset position, risk preferences, and corporate goals. This could be accomplished by replacing monetary payoffs with associated index numbers which reflect these preferences. This is the essence of the application of utility theory in the decision process.

CHAPTER II

THE NATURE OF UTILITY THEORY

The word "utility" connotes a "quality or state of being useful," or "profitableness to some desired end". Dictionaries further suggest its meaning to include "power to satisfy human needs", and "happiness". Students of economics, particularly in the specific area of marketing and consumer demand, will often encounter "utility" as a measure of desirability which a particular commodity has to the purchaser. In this sense the word "utility" is synonymous with "desirability", and involves choice under conditions of certainty. The utility theory to be described herein is quite the opposite, since it concerns one's preferences for various outcomes under conditions of uncertainty.

Most writers on utility theory attribute its origin to Daniel Bernoulli. As discussed previously, he suggested that an individual's value system is not adequately represented by monetary values alone. While Bernoulli made this observation in the eighteenth century, it was not until 1944 that a formal mathematical statement of an individual's value system was presented. At that time von Neumann and Morgenstern published their monumental volume Theory of Games and Economic Behavior (8) in which they set forth the conceptual framework for describing one's risk preferences and emotional biases with respect to monetary values.

This chapter will briefly outline the von Neumann and Morgenstern formulation of utility theory and illustrate its use as a drilling investment decision criterion. The current "state-of-the-art" of application of the theory in "real-world" decisions is given in the concluding section.

The von Neumann and Morgenstern Formulation

This derivation of utility theory is based upon eight axioms. Each axiom is essentially a mathematical statement of the elements of logic which most decision makers use in their daily decisions. The axioms are stated in terms of the utilities of various outcomes. The utility of a particular outcome represents a measure of desirability or usefulness which that outcome has to the decision maker relative to other possible outcomes. For example, if U represents an individual's utility of a successful well and V represents his utility of a dry hole, then the relation $U > V$ means that a producer is preferred to a dry hole. An interpretation of each axiom or significant point in the formulation is given by the parenthetical statements.

Consider a system Ω of (abstract) utilities $U, V, W, \ldots\ldots\ldots$ In Ω a relation is given $U > V$, and for any number $\alpha, [0 < \alpha < 1]$ an operation $\alpha U + (1 - \alpha) V = W$.

(The elements of the system Ω are the entities the worth of which we wish to measure for a particular individual. α is a real number and part of a set of real numbers $\alpha, \beta, \ldots\ldots$ the magnitude of which are strictly between 0 and 1. These elements in the set of real numbers are the probabilities that particular entities will occur. $U > V$ is interpreted as U is preferred to V by the individual. $\alpha U + (1 - \alpha) V$ represents a gamble having U as one outcome occurring with probability α , and V as the other outcome occurring with the complimentary probability.)

__AXIOM 1__: For any two U, V one and only one of the three following relations hold: $U = V, \quad U > V, \quad U < V$

(this is the "ordering" axiom and can be rephrased as: Given two alternatives, A and B, an individual either prefers A to B, B to A, or is indifferent to either alternative.)

<u>AXIOM 2</u>: $U > V, \quad V > W$ imply $U > W$

(This is the "transitivity" axiom. If a person prefers coffee to tea, and tea to milk, then he prefers coffee to milk.)

<u>AXIOM 3</u>: $U < V$ implies that $U < \alpha U + (1 - \alpha) V.$

(If U represents receiving $10 and V represents receiving $20, and receiving $10 is less preferable than receiving $20, this axiom then implies that receiving $10 with certainty is less preferable than accepting a gamble of obtaining $10 with probability α and $20 with probability $1 - \alpha$.)

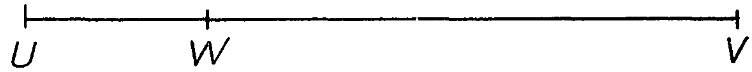
<u>AXIOM 4</u>: $U > V$ implies that $U > \alpha U + (1 - \alpha) V.$

(This is the dual of axiom 3. If U represents receiving $6 and V represents receiving $4, and receiving $6 is preferred to receiving $4, then the certain option of receiving $6 is preferred to that gamble that will either pay $6 with probability α or $4 with probability $1 - \alpha$.)

AXIOM 5: $U < W < V$ implies the existence of an α with

$$\alpha U + (1 - \alpha) V < W.$$

(Given three alternatives for which U is less preferable than W, which in turn is less preferable than V, then there is some combination of outcomes U and V which is less preferable than W. This connotation can be represented graphically by a line graph of the utilities of the three alternatives.



Increasing utility →

This axiom states that no matter how close W is to U there will be some gamble of U and V which will be less preferable than W. This axiom is the basis for the experimental portion of this research. The analogy to decisions regarding drilling investments is for V to represent the (most) desirable outcome of a producer, W is the alternative of reduced income from a farmout, and U is the alternative of a dry hole. This axiom states that there is some probability of a dry hole, no matter how small, that makes the gamble of drilling less preferable than the alternative to farm out.)

<u>AXIOM 6</u>: $U > W > V$ implies the existence of an α with

$$\alpha U + (1-\alpha)V > W$$

(This is the dual of Axiom 5.)

<u>AXIOM 7</u>: $\alpha U + (1-\alpha)V = (1-\alpha)V + \alpha U$

(This axiom states that it does not matter in which order the alternatives of a gamble are named or offered.)

<u>AXIOM 8</u>: $\alpha(\beta U + [1-\beta]V) + (1-\alpha)V = \gamma U + (1-\gamma)V$

Where β is any number in the interval $0 < \beta < 1$, and $\gamma = \alpha\beta$

(This axiom involves the algebra of combining. It states that it is irrelevant whether a combination of two constituents is obtained in two successive steps or in one operation.)

von Neumann and Morgenstern proved that the existence of these axioms implied the following correspondence (between utilities and numbers) and properties:

$$U \rightarrow \rho = \pi(U)$$

and

$$U > V \quad \text{implies} \quad \pi(U) > \pi(V),$$

$$\pi(\alpha U + [1-\alpha]V) = \alpha\pi(U) + (1-\alpha)\pi(V).$$

where U is a utility and $\pi(U)$ is the number which the correspondence $U \rightarrow \rho = \pi(U)$ attaches to it. The second and third relations are the properties of utilities which carry the relation $U > V$ and the operation $\alpha U + (1-\alpha)V$ into synonymous concepts for numbers. With these axioms and properties the system of (abstract) utilities Ω is one of numbers up to a linear transformation.

The von Neumann and Morgenstern formulation assumes individual preferences, and does not imply that a quantitative comparison of utilities between individuals can be made. It has the property (analogous to mathematical expectation) that if an alternative has several possible outcomes, say n of them, the utility of the alternative, $U(A)$, is the sum of the product of the utilities of each outcome, U_i , and their respective probabilities of occurrence, P_i . That is

$$U(A) = \sum_{i=1}^{n} U_i P_i \qquad i = 1, 2, 3, \ldots, n$$

where

$$\sum_{i=1}^{n} P_i = 1 \qquad i = 1, 2, 3, \ldots, n$$

What does this mathematical formulation of utility theory mean in the context of a decision maker's daily thought processes and logic?

First of all it suggests that _if_ he makes his decisions in strict adherence to the axioms, his preferences regarding the utility, or desirability, of various alternatives can be represented by a real-valued function, or utility curve. The function is monotonically increasing with preferability; that is, if his utility curve is expressed in terms of net profits the curve continually increases with increasing net profit. This of course is reasonable in that any small increase in net profit over an original amount is certainly more desirable than the lesser amount. An example of what this functional representation might look like is given in Fig. 2.

The utility values, or index numbers are dimensionless. The magnitude of the utility scale is arbitrary; however, after two points are initially fixed the curve is unique for the particular decision maker. The index number associated with any given profit is called the "utility" of that amount of profit. For the hypothetical utility function of Figure 2 the decision maker's "utility" for a $45,000 net profit is +5, and his "utility" for a $25,000 loss is -7.

Since the theory has the property of mathematical expectation, it is possible to calculate the "expected _utility_" of a particular decision alternative by multiplying the utilities of each outcome by its respective probability of occurrence and summing algebraically over all possible outcomes. The decision criterion is to accept the act if the expected utility is positive. If several alternatives are being considered, the criterion is to accept that act which will maximize expected utility. The origin of the utility curve represents the decision maker's "current status", or in terms of decision alternatives it represents taking no action in a particular decision.

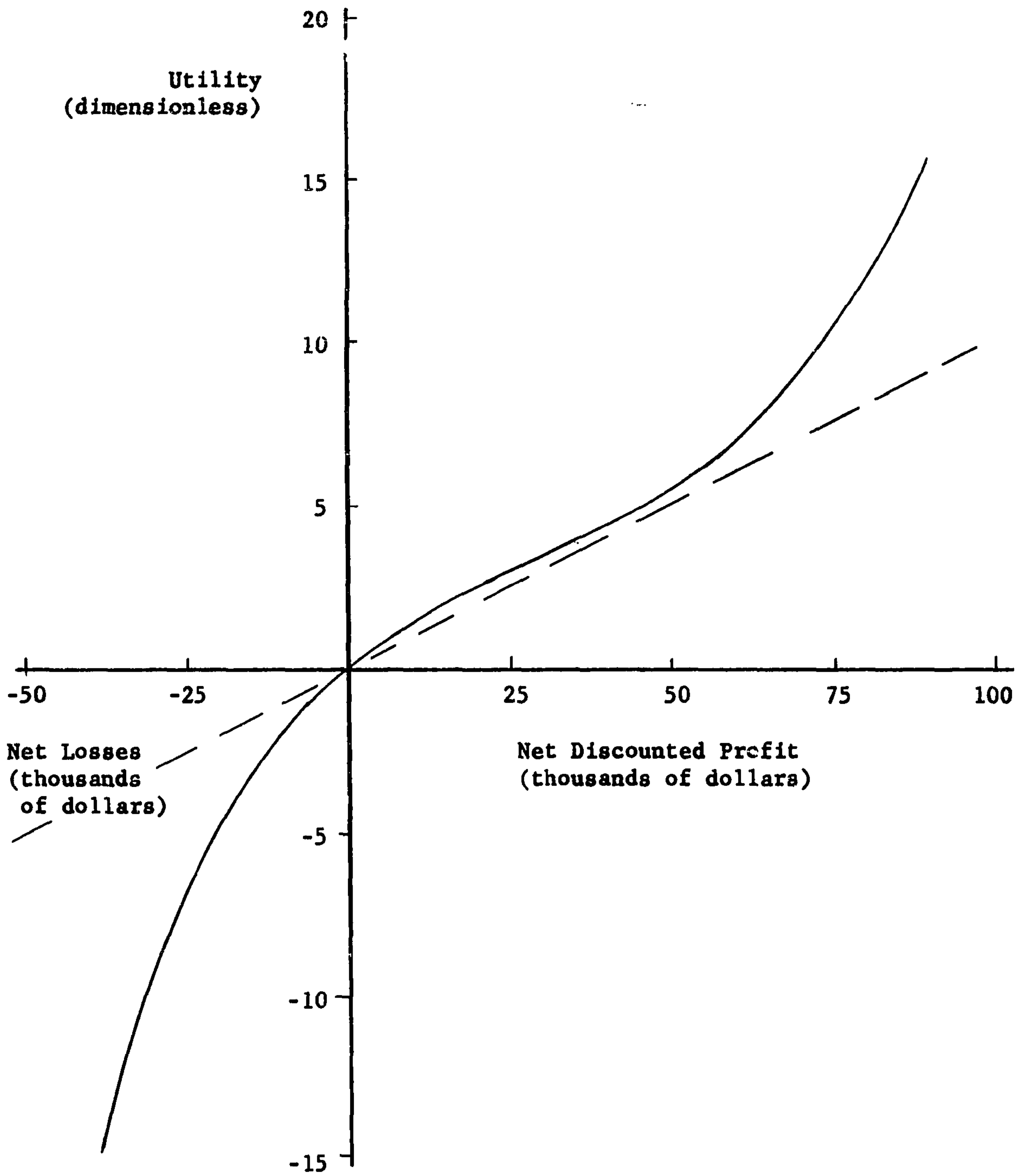


FIGURE 2 - Hypothetical utility function of drilling investment decision maker. (Dashed line represents decision maker's utility curve if he were completely impartial to monetary profits and losses.)

The parallel between expected monetary value and expected utility should be obvious. Instead of multiplying monetary payoffs by probabilities, the monetary payoffs are replaced by associated utility index numbers which are then multiplied by the same probabilities. There is one important difference, however. The magnitude of the utility index numbers for specific monetary payoffs depends on the particular shape of the individual's decision curve. It will be shown in the next chapter that the shape of the curve depends on the decision maker's risk preferences, asset position, and goals. If he were totally impartial to monetary payoffs, his utility function, or decision curve, would be a straight line passing through the origin (shown in Figure 2 as the dashed line). The departure from linearity reflects the degree of bias that the decision maker associates with various monetary payoffs. (A more detailed discussion of the relationship between various shapes of decision curves and specific biases will be given in the following chapter.)

Utility theory could thus be thought of as an extension of the concept of mathematical expectation, or expected value. von Neumann and Morgenstern noted this parallel with the observation - "We have practically defined numerical utility as being that thing for which the calculus of mathematical expectation is legitimate." Utility theory has the important advantage of systematically incorporating certain emotional biases of the decision maker into his value system.

Utility as a Drilling Decision Criterion

This section will illustrate the use of expected utility as a decision criterion for drilling investment proposals. The utility function, or decision curve given previously in Figure 2 will be assumed as representative for the decision maker that is reviewing this prospect.

The proposal is for the drilling of a 640 acre gas well in Ellis County, Oklahoma. The various outcomes which are possible, together with the estimated probabilities of their occurrence are given in Table 3. These outcomes, probabilities, and associated discounted net payoffs have been prepared by the professional staff of the company from studies of previous wells drilled in the general area of the proposed well. The decision alternatives are whether to participate with a 40 per cent working interest, farm out the company's leasehold rights while reserving a 1/8 of 7/8 ORI, or to be carried under the 150 per cent penalty clause of the unit operating agreement.

Having calculated the monetary payoffs for each outcome of the various alternatives, the decision maker then uses his utility curve of Figure 2 (p. 26) to determine his utility for each of the payoffs. For example, his utility for a $28,000 loss in the event of a dry hole is -8.3, and his utility for a $20,600 net profit from a completion with reserves of 2 BCF is +2.5. These and the remaining utilities are entered in the appropriate columns of Table 3. The "expected utilities" are obtained by multiplication of the utility of each outcome by the probability of its occurrence.

From Table 3 it is observed that being carried under the 150 per cent penalty has the highest total expected utility, and hence this alternative should be his decision. Of the three alternatives, participation with a 40 per cent working interest is the least preferable.

TABLE 3

EXAMPLE OF EXPECTED UTILITY CONCEPT

Proposal: 640 acre Gas Unit in Ellis County, Oklahoma

Possible Outcomes	Prob. of Occurrence of Possible Outcomes	Decision Alternatives								
		Participate with 40% Working Interest			Farm Out Leasehold, Retain 1/8 of 7/8 ORI			Penalty Clause - Back in with 40% WI after Recovery of 150% of Invest.		
		Payoff	Utility	Expected Utility	Payoff	Utility	Expected Utility	Payoff	Utility	Expected Utility
Dry Hole	0.35	$-28,000	-8.3	-2.90	$ 0	0	0	$ 0	0	0
2 BCF*	0.25	20,600	2.5	0.63	5,400	0.9	0.23	5,200	0.9	0.23
3 BCF	0.25	42,200	4.4	1.10	8,100	1.2	0.30	19,700	2.4	0.60
4 BCF	0.10	63,800	7.4	0.74	10,800	1.4	0.14	36,600	4.0	0.40
5 BCF	0.05	85,500	14.0	0.70	13,400	1.7	0.09	55,500	6.1	0.31
Total Expected Utility →				0.27			0.76			1.54

*Figures are gross ultimate recoverable reserves

Parameters: Gross Producer Well Costs: $100,000 (Including lease equipment)
Gross Dry Hole Costs: $70,000
Company's Lease Holdings in Unit: 256 net acres (40% WI)
Payoffs represent discounted net profits using 10% discount rate and 20 yr. life
Tax rate - 5%, Royalty - 1/8, Annual Prod. Rate - 5% of reserves.

Review of Current Applications of Utility Theory

Since the introduction of a formal utility theory in 1944 much has been written about the concept. Most writers of current decision theory literature acknowledge the intrinsic superiority of utility theory as a decision criterion. None-the-less there has been considerable controversy about whether a functional representation of an individual's preferences can even be made. If so, will a rational person act in a manner which will maximize his expected utility? For example, some have argued that if one of the outcomes is overwhelmingly bad, such as death or bankruptcy, then people do not follow their normal risk preference patterns. Proponents counter with the example that most people continually and routinely choose to cross a busy intersection during rush hour (which involves the fair certainty of a safe crossing together with some small, but finite, chance of being run over) to the less desirable but riskless alternative of waiting for two hours to cross when the rush is over.

As another example, Baumol (11) argues that the assumptions of the von Neumann and Morgenstern theory restricts one's choices. He states: "Once he has made up his mind on a few things, the rest is decided for him by the rules. From his choices among some limited sets of items we know how he will react to the rest, and there is no apparent reason why choice should be so circumscribed in fact."

These types of arguments are difficult to resolve until the theory is actually tried under "real-world" conditions. It is significant to note that use of utility theory in today's business community is virtually non-existent. The problem in implementing utility theory is that at present there are no effective methods to construct or determine the utility curve. Therefore, the resolution of certain philosophical questions about utility theory cannot occur until we first determine a way of obtaining the utility functions.

Previous research on this problem has centered on the development and use of testing procedures to obtain the data needed to construct a utility curve. These procedures generally have been based on offering the decision maker a choice between a gamble having a desirable outcome (A) and an undesirable outcome (C), or a no-risk alternative (B) of intermediate desirability. The testing would seek to determine the decision maker's point of indifference between accepting the gamble (A occurring with probability α and C occurring with probability $1-\alpha$) or the no-risk alternative. The indifference point represents an equality of the decision maker's utility for the gamble and the no-risk alternative; that is

$$\alpha \times U(A) + (1-\alpha) \times U(C) = U(B) \qquad \ldots\ldots [1]$$

By arbitrarily assigning numerical values to two of the above utilities the third could be computed. With careful design of the testing sequence, these three numerical utilities would be used to compute successive utilities. After determining a sufficient number of utilities, a utility curve would be drawn through the data points. These testing procedures, while successfully suggesting that a decision maker's preferences can in fact be represented by a utility curve, have contained certain disadvantages.

There is one principle shortcoming of the two notable attempts to construct utility curves in laboratory settings - the testing was so carefully controlled as to render the transformation of the results or techniques into real-world situations virtually impossible. The pioneering work in this regard was done by Mosteller and Nogee in 1951 (9). Using one group of 5 Harvard undergraduates and another group of 5 National Guardsmen, they were able to construct utility functions from each individual's responses to sets of gambles. The members tested used their own money; however, the monetary amounts of the gambles did not exceed $8. Their experimental procedure consisted of keeping the odds for a particular gamble the same but varying the maximum gain to find an indifference point. They used as justification of this technique the fact that people can normally make a decision in terms of money easier than in terms of probability. One of their conclusions was that it was not unreasonable to accept the notion that people behave in a manner that will maximize expected utility. They did find, however, that their subjects were not as consistent about preference and indifference as postulated by von Neumann and Morgenstern, but had a graded response that gradually increased the frequency of risks taken as the value of the risk increased.

In 1957, Davidson, Suppes, and Siegel reported the results of a different test procedure in their book <u>Decision Making: An Experimental Approach</u> (10). In this experiment the probabilities were held constant and the payoffs were fluctuated to find indifference points. This approach was chosen to remove the possibility of introducing subjective probabilities. Monetary values utilized were less than one dollar. Since drilling decisions have varying probabilities and obviously involve more money this test procedure is not applicable for actual drilling decision conditions.

Two attempts to construct utility curves under actual management decision conditions have been reported in the literature. Each of these has been only partially successful, apparently due to the inability of the respondents to grasp portions of the testing procedures. The first of these attempts was reported by Grayson in his book Decisions Under Uncertainty, published in 1960 (2). He devised a testing procedure which he gave to a number of independent oil company personnel. His procedure was to propose a simple investment and ask the respondent if he would accept or reject the proposal, given the stated probabilities. For example, the respondent would be asked if he would accept or reject a venture costing $10,000 that had a total payoff if successful of $110,000, with a probability of success of 0.60. Depending on the person's responses the probabilities were varied until the indifference point was reached. Then the monetary payoffs were changed and the process repeated. Generally he was able to construct utility curves from the responses he obtained, but he observed that most decision makers were not accustomed to making decisions solely on the precise discernment of acceptable and unacceptable probabilities. In fact, one of the participants could not respond at all to the experiment, saying that he could not conceive the probability relationships.

The second and most recent attempt (1963) to construct utility functions under applied conditions was done by Green (12) using 16 middle management personnel in a large industrial firm. These personnel represented four major divisions of the firm: production, sales, finance, and research. His testing procedure consisted (in part) of presenting various investment proposals, with the possible outcomes expressed in terms of rate of return. The individual was then asked to indicate how high the probability associated with the larger return had to be before he would recommend adoption of the investment proposal. From their responses he was able to construct utility functions (in terms of rates of return rather than dollar payoffs) for each person. Green also noted that the respondents had trouble conceptualizing the problem, particularly the probability aspects. He further commented that despite the problems of designing a suitable test procedure, the non-linear shape of the utility functions so constructed point out the inadequacy of present capital budgeting criteria based solely on monetary values.

Direct application of the von Neumann and Morgenstern theory in a testing procedure has a number of weaknesses from a theoretical viewpoint. Their model requires that the individual view the probabilities as objective if a true utility curve is to be obtained. If an individual subjectively appraises the odds, then his responses may include an unknown mixture of subjective probabilities and utilities. The theory also requires that the set of alternatives from which a subject chooses must include all finite probability combinations of these alternatives; hence, an infinite number of comparisons. Any finite testing procedure which attempts to derive utility functions in the von Neumann and Morgenstern sense will inherently contain these limitations. How restrictive these limitations might be has not been determined to date because of other, more critical weaknesses in previous testing procedures.

As a concluding comment to this chapter on the nature of utility theory it is well to summarize the principle aspects. The von Neumann and Morgenstern theory provides a conceptual framework within which a functional representation of an individual's preferences may be constructed. The theory does not prescribe his preferences or the rules of consistent decision making, but merely is a convenient way of representing them. The problem in implementing utility theory into "real-world" conditions is that no satisfactory method of originally constructing the utility function has been developed as yet. Attempts thus far to construct utility curves have consisted of testing procedures using a series of hypothetical or test wagers. The tests have contained certain weaknesses which have prevented the use of the results in actual decision situations. Consequently, there appears to be a complete lack of any formal applications of utility theory as a decision criterion in the business community today.

CHAPTER III

THE DRILLING DECISION EXPERIMENT AND RESULTS

The research being summarized in this study had the following specific objectives:

1) The design of a suitable testing procedure that would provide data for the construction of utility curves for management personnel involved in drilling investment decisions.

2) Determination of the applicability of the test by actual use with oil company drilling investment decision makers.

The guidelines which were initially established to reach these objectives were: 1) use of actual drilling decisions in the testing procedure, and 2) presentation of these decisions to the decision makers in a manner similar to that in which actual drilling prospects are presented. These guides were established in an attempt to devise a procedure which would be realistic and representative of "real-world" conditions.

The first portion of this chapter describes the test and the procedure for its presentation. After the test was developed it was presented to a number of drilling decision makers to ascertain its usefulness. The method of construction of the utility curves from the test data is outlined in the second portion of the chapter. The results of the presentation of the test are summarized in the concluding portion.

The Decision Test

The decision test that was formulated in this research was similar in nature to previous attempts in that a series of test gambles, or decisions, were presented to the decision makers. And, as in previous test procedures, the point of indifference between accepting or rejecting the gamble was determined. This decision test, however, differed in certain important ways from previous techniques. In place of hypothetical investments actual drilling proposals were used. The gamble then consisted of "drilling" a well, with the desirable outcome (A) being a successful completion and the undesirable outcome (C) being a dry hole. The no-risk alternative was "not drilling", with the understood assumption that the acreage would be processed by a farmout or similar means.

Ten test decisions were prepared from actual field conditions. Each proposal contained at least two potential drilling locations together with related information regarding reserves, allowables, etc. These proposals were presented verbally while the decision maker followed on individual copies of the proposal. Any specific questions concerning the geology, type of production, performance of existing wells, etc. were answered. After the participants had studied the prospect for a few moments they were asked the following basic question:

> "There are several potential drilling locations in this field. In view of the investment and degree of risk stated, what is the minimum amount of net profit or reserves that you feel you must obtain to drill any of the potential drillsites?"

The minimum net profit which they would choose represents the payoff of outcome (A) for which they are indifferent between the gamble (decision to drill) and the no-risk alternative (not drill - farm out instead). Note that this is the second feature which distinguishes this test procedure from some of the previous attempts. Rather than stating an investment and payoff and varying the probabilities to locate an indifference point, the investment and probabilities were stated and the payoff was selected by the participant to locate his indifference point. This technique is believed to more realistically represent a drilling investment decision for the following reasons:

1) The degree of risk for a particular drilling proposal is determined by the quality and amount of geologic and engineering data available. Therefore, a testing procedure in which probabilities are varied for a given investment is not representative of drilling decisions.

2) The investment is specified once the depths are given, and the decision alternatives are set (i. e. drill, farm out, etc.).

3) The remaining variable which influences the decision maker to drill or farm out is the amount of reserves (and thus net profit) which is anticipated for the prospect.

The technique is the natural extension of such comments often heard in drilling decision groups as "I think we should be looking at a minimum of 100,000 bbls. reserves to consider drilling", or "This is a pretty risky prospect; therefore, we should try to get at least $2 net profit per $1 invested". Since each proposal had at least two potential drillsites, the decision was not whether a participant would drill a particular well. Instead he was, in effect, supplying a prior criterion such that when any particular location was subsequently evaluated, the decision would have already been set depending on whether it met the criterion or not.

The ten test decisions were selected from fields in Oklahoma and Kansas. Each was identified by county and geologic province, but actual field names, well names and operators, and township and range identifications were not given. Investment well costs ranged from $40,000 to $200,000. All of the proposals were based on a full 100 per cent working interest. The degree of risk ranged from an exploratory proposal to in-fill development proposals. Brief descriptions of each of the ten drilling prospects are given in Table 4. An example proposal was also prepared to illustrate the computations and the general layout of the proposals.

All of the pertinent data associated with each drilling proposal were contained on separate sheets of a portfolio. Each participant was given a portfolio during the testing procedure. An example of the general layout of each proposal is given in Figure 3. A map of the wells drilled in the field was given. The map included geologic interpretations applicable to selecting drilling prospects (such as structure, isopach) in the particular field. In the example of Figure 3 an isopach interpretation is shown. Potential drilling locations for the example proposal of Figure 3 are indicated by the open circles inside the 10' net pay contour. Various data regarding depths, allowables, investments, etc. were given in the Pertinent Data section to the right of the map.

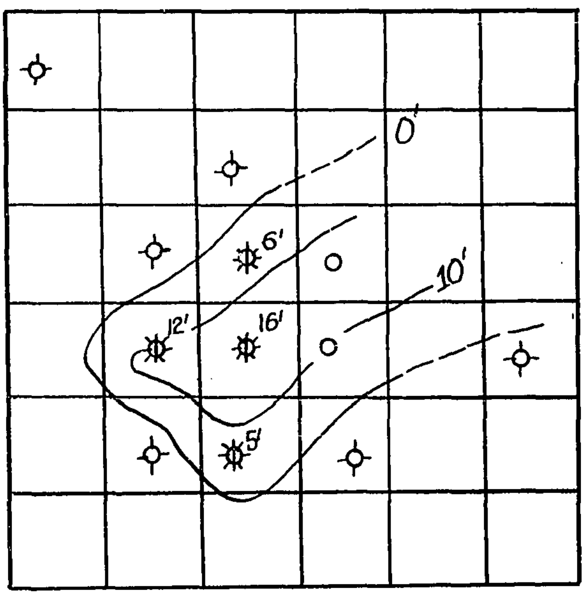
The Pertinent Data section also included a parameter called "Reliability of Interpretation". This was a number strictly between 0 and 1 which represented the risk factor for the particular prospect. It was intended as an overall, subjective estimate of the reliability of the geologic interpretation that was being presented as the basis for the drilling proposal. Note that this probability estimate was <u>not</u> intended as the probability that a particular well would be a successful completion. It was instead, the probability that a proposed well would

TABLE 4 - DESCRIPTIONS OF THE TEN DRILLING PROPOSALS

Proposal No.	County (State)	Pay Zone	Investment Producer	Investment Dry Hole	Type Field	Risk Factor	Brief Description
1	Finney (Kansas)	Multi-pay Penn., Miss.	$70,000	$50,000	Oil	0.25	Exploratory proposal, 6 pay zones, Risk based on previous wildcat successes.
2	Stafford (Kansas)	Arbuckle	$40,000	$30,000	Oil	0.60	Seismic "high" prospect. Risk based on reliability of seismic.
3	Haskell (Kansas)	Lansing	$50,000	$30,000	Oil	0.70	Proposals are 80 acre offsets. Structure and control well defined.
4	Morton (Kansas)	Morrow	$70,000	$50,000	Gas	0.60	In-fill proposals. Risk based on interpretation of structure.
5	Harper (Okla.)	Tonkawa	$55,000	$30,000	Oil	0.55	Proposals are 40 acre offsets. Risk due to unknown stratigraphy.
6	Harper (Okla.)	Morrow	$80,000	$50,000	Gas	0.40	Proposals are offsets. Interpretation is poor. Some wells have poor capacities.
7	Blaine (Okla.)	Morrow	$185,000	$150,000	Gas	0.40	Small field, little geologic control Isopach interpretation speculative.
8	Kingfisher (Okla.)	Oswego	$80,000	$50,000	Oil	0.60	In-fill prospects. Isopach extended by recent completion
9	Canadian (Okla.)	Morrow	$200,000	$150,000	Gas	0.60	Offset proposal in 11 well field. Fair control, stratigraphy unknown
10	Latimer (Okla.)	Atoka	$150,000	$90,000	Gas	0.70	Good control, high per-well reserves 3 year shut-in anticipated.

FIGURE 3

GENERAL LAYOUT OF DRILLING PROPOSALS



MORROW SAND ISOPACH

✲ Morrow gas well

○ Potential drilling location

PERTINENT DATA

Location ______________

Pay ______________

Geologic Control ______________

Depth ________ Spacing ____

Allowable ______________

Length of Shut-In ______________

Royalty ____ Prod. Tax ____

Reservoir Prod. Drive ______

Investment

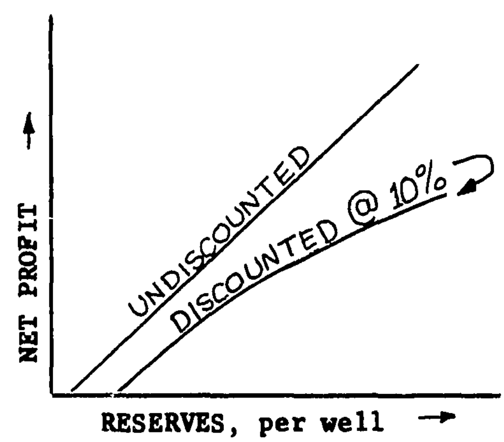
Producer ______

Dry Hole ______

Reliability of

Interpretation 0.40

TABLE OF WELL RESERVES, FLOW POTENTIALS, ETC.



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encounter the amount of reserves indicated by the given geologic interpretation. The Reliability of Interpretation was determined by the writer from his previous knowledge of the fields associated with the drilling proposals, and the value assigned was thought to be realistic for the conditions involved in each field. The Reliability of Interpretation factor will occasionally be designated as the "risk factor" in the remainder of this study.

The lower left portion of the proposal contained information concerning reserves and performance of existing wells, either by a list or with a frequency bar graph. The net profit curves were plotted as functions of per well reserves. The upper, linear function represented undiscounted net profit; the lower, non-linear function was discounted net profit using a 10 per cent rate of discounting. The discounted net profit curve included the effects, if any, of shut-in delays.

Care was taken in the preparation of the drilling proposals to insure that all the information and interpretations were representative of actual field conditions. Specific values for all parameters affecting net profit, such as crude price, operating expenses, etc. were used in the computation of the net profits. Reserve estimates were representative of the field in each case. Some of the proposals were taken from fields which were being actively developed, while some fields had been completely developed at the time. In the latter case, the sequential development of the field was studied, and the proposal based on a point in time when it was only partially developed. All proposals, however, were based on actual conditions in an attempt to reflect the problems of incomplete geologic control, poor reserve data, etc. which exist in many daily drilling decisions.

Prior to commencing the actual decision test, a brief slide presentation was given to explain utility theory and outline the goals of the test. Then, the example proposal was reviewed to indicate the method of computation of the net profit curves and to illustrate the general layout of the test decisions. At this time the following points were emphasized:

1) Each participant was to presume that he was making the decision for his company.

2) All responses would be confidential, with no references made to individuals or companies that participated. It was also pointed out that there were no right or wrong answers; this was not a test of their decision making ability but rather a test of whether this decision test procedure was realistic.

3) It was requested that the reliability of interpretation be accepted as stated on the presumption that it was the best estimate of their professional staff.

4) The assumption that the participant's company held valid leasehold rights under all proposed drillsites; factors such as lease expirations, offset drilling commitments, competitive position, and federal income tax were not considered.

5) The participants could use whatever capital budgeting criteria they wanted, and were free to make pencil computations before reaching their decision.

6) Their indifference point between "drilling" or "not drilling" could be given on the answer sheet in terms of either reserves, undiscounted net profit, or discounted net profit. It was clearly stated, however, that the discounted net profit value would be used for the computation and construction of the utility curve.

7) If they felt that the value of minimum reserves or net profit for which they would consider drilling was larger than indicated on the net profit graph, they were permitted to state the higher value.

After answering any further questions the ten drilling proposals were presented. The order in which they were given was not as listed in

Table 4, but rather in a manner which would intermix the ranges of investment and risk. The testing was conducted in the offices of each company that participated. The entire decision test procedure required slightly less than two hours to complete.

The procedure used to arrange the participation of the decision makers of the various companies was to first contact one person in the organization that was a member of, or closely associated with, the decision group of the particular office. At that time the decision test procedure was reviewed, and some of the test decisions were shown to him. It was stated that their responses would be confidential. It was also emphasized that it was not the company or any of their decision makers that were being tested or judged; - rather, that the test procedure itself was on trial and they were merely trying or testing it. After this initial meeting a mutually satisfactory date would be arranged for the actual test procedure. Five different oil companies were contacted in this manner, and four agreed to participate in the decision test. The participants in the testing procedure were all members of the group making decisions on drilling investments for their company. The participants were selected in a manner that would insure at least some familiarity with the general geologic areas covered by the test proposals.

Construction of the Utility Curve

The responses of each participant consisted of their indifference point between "drilling" and "not drilling", expressed in terms of discounted net profits. These responses are tabulated for each participant in the Appendix. Also included in the Appendix is the utility curve constructed from each participant's responses.

The method of computation used to convert their responses to utilities is similar to that used by Grayson (2). An example is given here using the actual test results of one of the respondents. His responses are shown in the following table:

TABLE 5

RESPONSES OF PARTICIPANT A-4

Proposal Number	Investment Producer	Investment Dry Hole	Reliability of Interpretation (Risk Factor)	Indifference Point Disc. Net Profit
3	$ 50,000	$ 30,000	0.70	$ 74,000
4	70,000	50,000	0.60	135,000
5	55,000	30,000	0.55	92,000
8	80,000	50,000	0.60	115,000
1	70,000	50,000	0.25	175,000
6	80,000	50,000	0.40	95,000
10	150,000	90,000	0.70	130,000
7	185,000	150,000	0.40	300,000
2	40,000	30,000	0.60	76,000
9	200,000	150,000	0.60	165,000

(Proposals are listed in the order they were presented.)

By virtue of the utility curve being unique up to a linear transformation, the utilities of two payoffs could arbitrarily be specified. The utility of a $50,000 loss was set at -10 and the utility of no action (rejecting the gamble) was set at 0. This convention was followed in the computation of all the responses listed in the Appendix. The utility associated with the payoff, U(A), could then be computed using Equation 1 (p.31) for the four proposals involving $50,000 losses. For example, the utility of the + $135,000 payoff specified for Proposal 4 is computed as

$$0.6 \times U(+\$135{,}000) + 0.4 \times U(-\$50{,}000) = U(\$0)$$

$$0.6 \times U(+\$135{,}000) + 0.4 \times (-10) = 0$$

or:

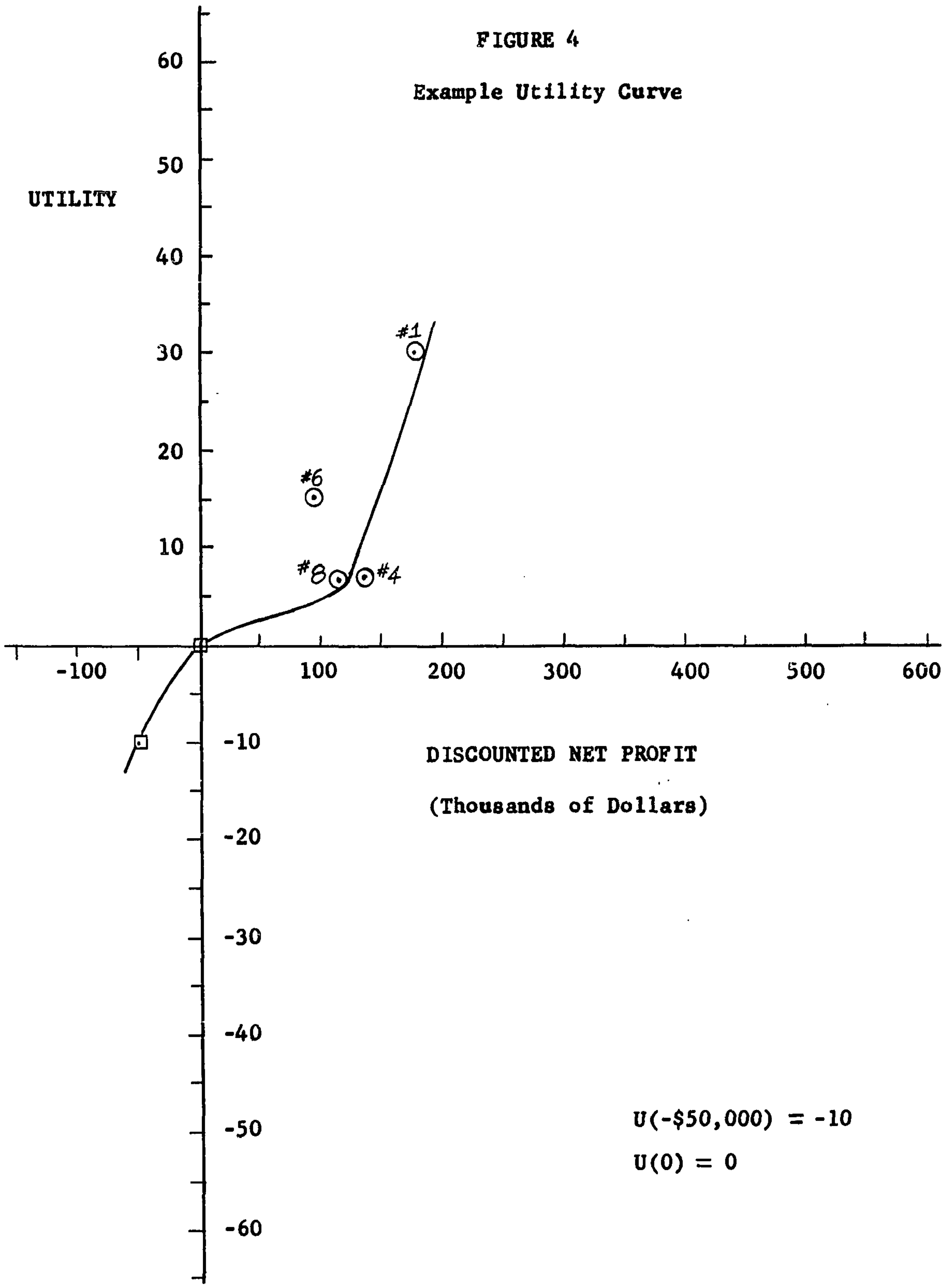
$$U(+\$135{,}000) = 6.67$$

Similar utilities are computed for the payoffs given in Proposals 8, 1, and 6. Six utilities are now known and plotted to give the general shape of the curve (Figure 4). The curve is extended for larger losses and payoffs by use of utilities read from the curve within the range of the original six points. In this example the original six points were sufficient to define the curve up to a net profit of $175,000. The utility of +$130,000 in Proposal 10 was then read from the curve and used in Equation 1 to compute the utility of a loss of -$90,000. This procedure was possible because of the overlapping of net payoffs between the various proposals.

Note that the indifference point of $95,000 stated for Proposal 6 was less than the $135,000 he required for drilling Proposal 4 which had the same dry hole cost. Yet Proposal 6 had more risk (0.40 reliability of interpretation versus 0.60 for No. 4) which would suggest the choice of a higher minimum net profit to offset the added risk. This situation suggests either an intransitive decision or a strong bias on the part of the participant for one of the proposals. To proceed with the computation of the participant's utility curve required a judgment as to which of the two responses was the inconsistent or biased decision. For Proposal 5 involving only a $30,000 potential loss he specified a minimum of $92,000. For Proposals 4 and 8 (both with $50,000 losses and risk factors of 0.60)

FIGURE 4

Example Utility Curve



he required at least $115,000 to drill. These three responses suggest that his indifference point of $95,000 for Proposal 6 was inconsistent with respect to his stated preferences for the other three proposals. Therefore, his response for Proposal 6 was judged to be the inconsistent decision, and the utility computed therefrom was not used for the plotting of the curve. The completed utility curve for this participant is given in the Appendix on page 80.

Summary of Results of Testing Procedure

The responses of the participating decision makers were generally enthusiastic. In most cases they wanted to see their utility curves afterward to evaluate their decision preferences with respect to others in their company. They were generally unanimous in expressing a need for some criterion to account for biases in a consistent manner. Their willingness to participate in the testing procedure appeared to result from this recognition of the inadequacies of the capital budgeting criteria they were then using.

Most participants had a tendency to be overly cautious in the first few drilling proposals by examining every factor given in great detail. Thereafter, it appeared that they directed their attention primarily to the investment and risk factors. Several commented that in the first few proposals they had been too concerned with the details of the prospect. With the exception of one person, it was felt that all the respondents clearly understood the notion of stating an indifference point. After careful explanation it was also felt that they recognized the important fact that they were making a general decision rule for the field, rather than a decision for a particular location.

The decisions made on some proposals by the participants were often relatively inconsistent. That is, for some drilling prospects the participant associated a greater or lesser value to the potential profits with respect to his choices on other decisions. This was illustrated in the preceding section by the participant's response given for Proposal 6. It is conceivable that the participants may have assessed the reliability of interpretation as being higher or lower than the value stated whenever these inconsistencies occurred. As an example, if the participant discussed previously felt that the reliability of interpretation for Proposal 6 was 0.7 rather than 0.4 his indifference point of $95,000 would be consistent with respect to his responses for Proposals 4 and 8. This would result from the fact that he would have then judged Proposal 6 to have less risk than Proposals 4 and 8; therefore, he would drill the proposal for less minimum profit ($95,000 versus $115,000 and $135,000 for Nos. 8 and 4 respectively).

It is to be noted, however, that in the testing conducted in this research there was no single proposal in which <u>all</u> participants made inconsistent decisions. This suggests that the reliability of interpretation stated was reasonably representative of the risk involved. Further, it was clearly stated in the testing that respondents were to accept the assessment of risk given for each proposal as being the best estimate of their professional staff. It is believed that in most instances the inconsistent responses were not caused by the reliability of interpretation factor. A more feasible explanation of the inconsistent responses seems to be that perhaps it is quite difficult to be completely transitive in one's decisions without a formal criterion such as expected utility.

Another interesting point was evident in the testing with respect to the responses given for Proposal 10. This was perhaps the best prospect in the entire series, with developed per-well reserves of three or four times the amount normally stated as the indifference point. However, the gas field was shut-in with an anticipated delay of three more years before gas sales would be commenced. Despite the large per-well reserves and the fact (which was clearly stated) that the discounted net profit curve included the sales delay, all but a few participants required a higher "minimum" to drill this prospect - relative to their preferences expressed on other proposals. Inclusion of this prospect was deliberate to see how the decision makers react to a drilling investment with deferred income. If a decision maker uses a discounted net profit criterion, the effects of deferred income are considered in the discounting. The responses to this testing suggest that despite this fact many decision makers still have strong biases about shut-in delays. These biases might be caused by such things as the amount of work required to commence gas sales (FPC hearings, etc.) and the simple nuisance factor of added clerical and accounting work.

The results of the testing also provided interesting comparisons among decision makers in the same company. Figure 5 shows the utility curves of two decision makers in Company A. Decision maker A-2 verbally expressed a preference for a "mix" of drilling investments which would include less expensive, low ultimate profit type investments as well as the high profit prospects. His responses, and hence his utility curve reflect this preference in a profit range less than $125,000. On the other hand decision maker A-4 had little utility or preference for drilling wells for potential profits of less than $125,000.

FIGURE 5

Comparison of utility curves of Participants A-2 and A-4

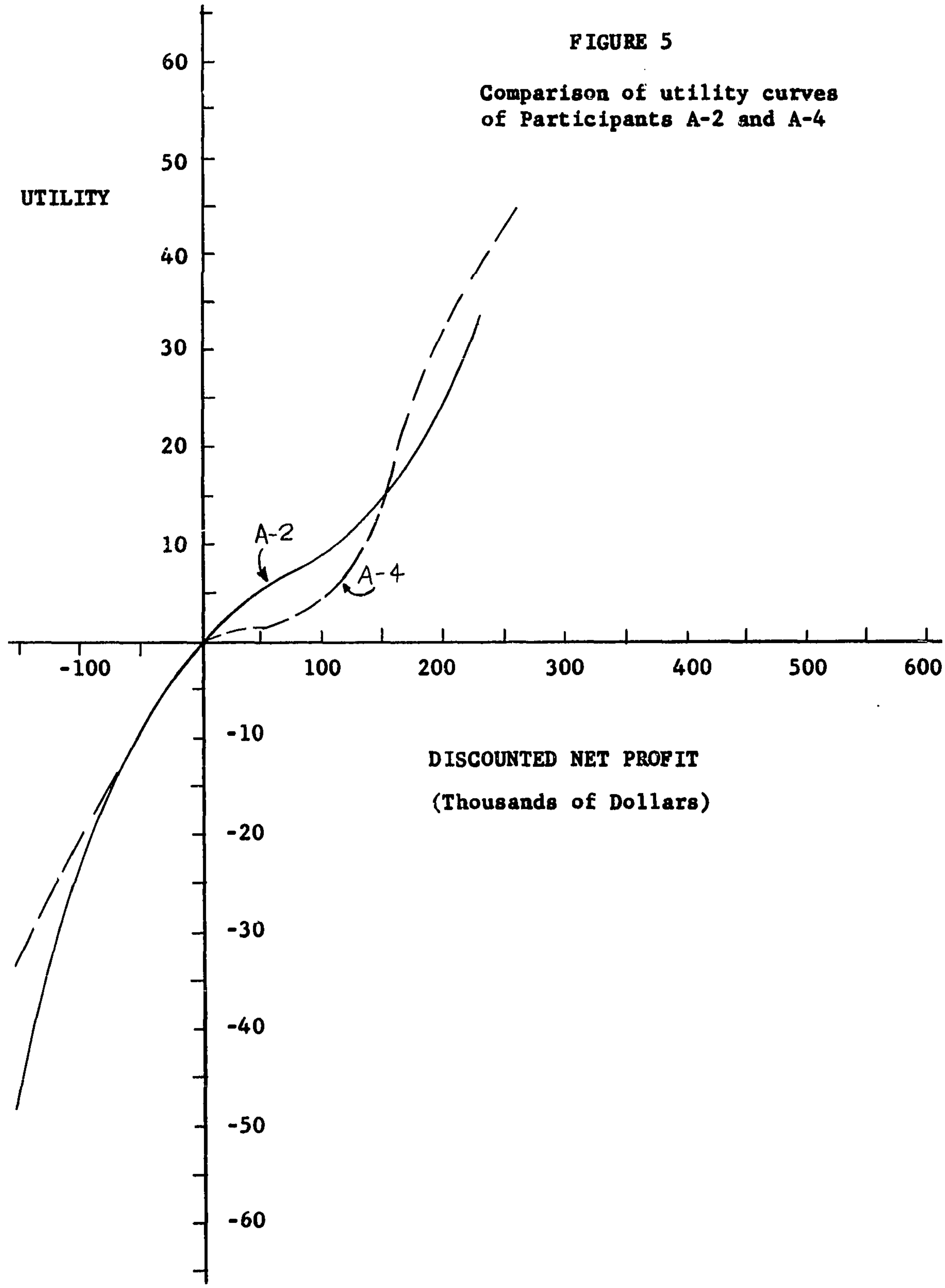
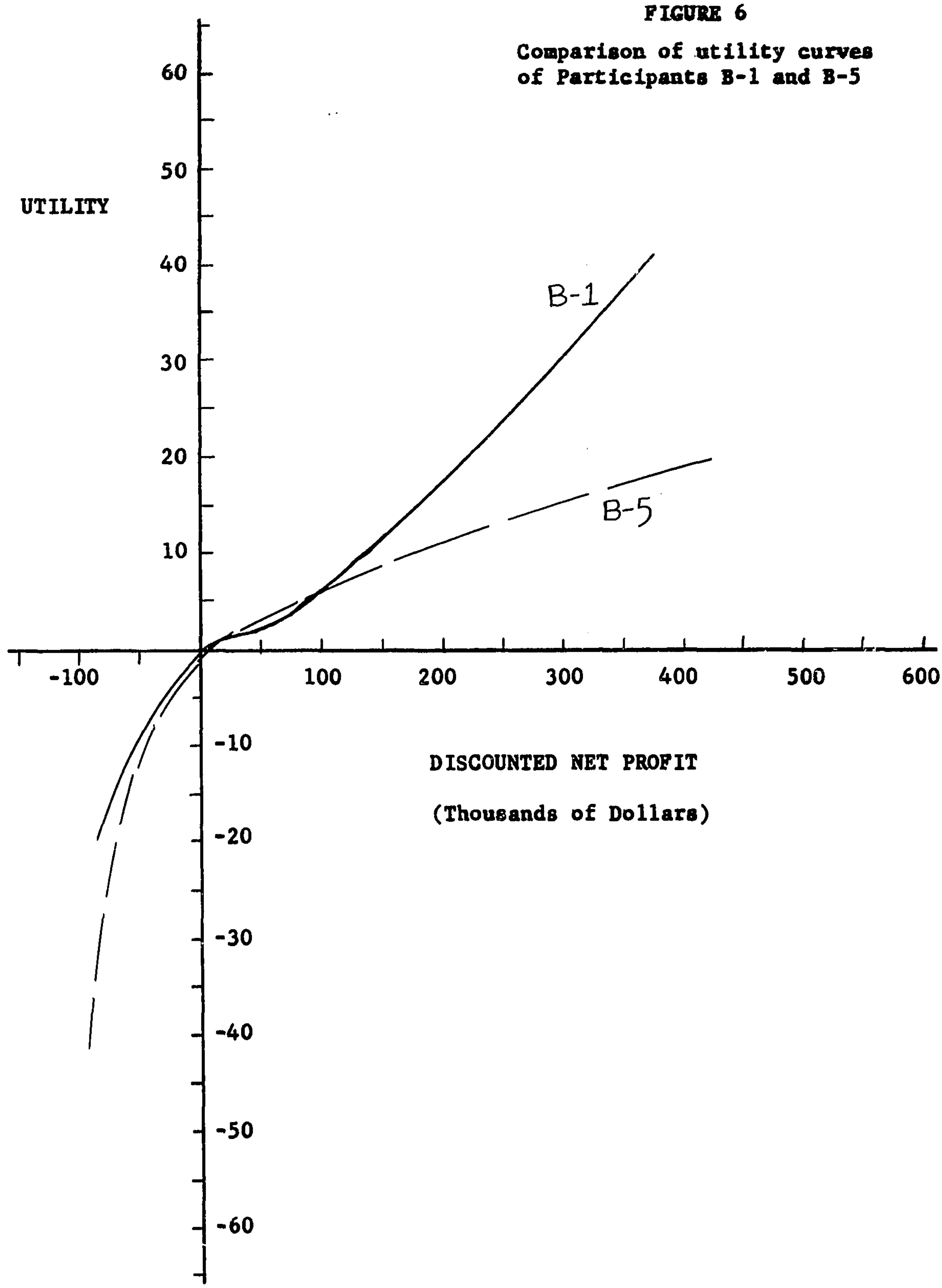


Figure 6 gives another comparison between two decision makers in Company B. From the shapes of their utility curves, decision maker B-1 has a much greater preference for profits exceeding $150,000 than does B-5. Stated conversely, B-5 appears to be more conservative. As an example, Proposal 6 had a potential dry hole loss of $50,000 and a risk factor of only 0.40. Participant B-1 stated he would drill this prospect for a minimum profit of $175,000, while B-5 stated that he would require at least $250,000 profit to consider drilling in the field.

Another comparison was made for each group of decision makers and is shown in the Appendix as the Composite Decision Curve. The data used to construct this curve were the arithmetic average of the indifference points stated by each participant in the group for each proposal. This curve was constructed to see if an average of all the individual preferences would be a consistent set of decisions, even though some of the participants were inconsistent on some of their responses. For example, each of the four participants of Group A had inconsistencies but all the "average" points generally fall on a feasible composite decision curve. This might represent an ultimate group decision which might be made by Group A. While this comparison seems intuitively valid, it must be emphasized that utility theory is based on individual rather than group decisions. The problems and nature of group or social choices are quite complex and the composite decision curve is not presented with any claim of theoretical justification. It does, however, raise the question about group action as a means to achieve a greater degree of consistency.

FIGURE 6

Comparison of utility curves
of Participants B-1 and B-5



As a general summary of the test results, it appears that the procedure for testing appears adequate to determine a utility curve for a drilling investment decision maker. In many cases, stated biases or preferences of the participants were reflected in the shapes of their utility curves. This suggests that the test procedure is representative of the type decisions made in actual situations. The utility curve constructed from the responses given in a test procedure such as this should be usable for "real-world" decisions. It should be noted, however, that many of the curves have similar shapes in the third quadrant (net losses). This is because the utility of a $50,000 loss was set at -10 for all participants, together with the fact that only three other values of net losses were given. Therefore, the specific results of this set of drilling proposals are not sufficient to clearly define this portion of the curve. This problem could be eliminated by using a wider range of potential losses in subsequent drilling proposals.

Several suggestions for improvement or modification of the testing procedure became evident in the experimental phase of this research. Since the writer was completely familiar with all the fields involved, it was not too difficult to answer any specific questions about the fields, the geology, the producing characteristics, etc. Unquestionably, the exploratory drilling prospect was the most difficult prospect to present. It is customary to consider wildcat proposals in terms of ultimate reserves which might be discovered rather than per-well reserves, and this approach was used for the test decision. The participants were then asked to indicate the minimum amount of ultimate <u>field</u> reserves which they would require to justify the high risk involved in drilling the wildcat. Considerable explanation was usually required before the participants were able to evaluate the proposal. Some of the trouble in presenting this drilling prospect may have resulted from the fact that some companies apparently evaluate their exploratory projects in a different manner.

One participant suggested that an additional discounted net profit curve, using a 15 per cent rate of discounting, be included. This could be added easily in the design of future tests. However, care must be exercised to insure that the format will not favor a particular monetary decision criterion such as rate of return.

Another participant asked if the writer was attempting to trap or trick him by the non-sequential order in which the decisions were presented. This was perhaps a valid criticism, and the writer feels that future test decisions should be arranged and presented in numerical order.

Some respondents felt they could have made better decisions if they were given more time on each proposal. The testing time was limited to minimize the time requirements of the participants. This approach was felt to be representative of actual decision conditions. The logical solution when using this test procedure within a company is to allow a time equivalent to that allotted for consideration of each actual drilling proposal.

Several participants stated that they were consciously evaluating whether they believed the stated reliability of interpretation, or risk factor, and that in some cases they felt that it should be either higher or lower. In the ensuing discussion, the suggestion evolved of letting each participant state his indifference, as well as the risk factor used as a basis for his decision. From a mechanical point of view the procedure used herein for computing utilities would be unaffected. An approach such as this suggests that the decision maker must assess the risk as well as completing the "value phase" of the decision. This is in contrast to most decision situations where the decision maker must rely upon the risk assessment prepared by his professional staff. A further complicating factor is that the proposals would have to include a larger amount of geological and engineering data to permit a reasonable analysis of risk. Such a modification of the testing procedure developed in this research does not appear desirable.

The participation and enthusiasm of the respondents improved in the upper levels of management. It was apparent that when the senior management personnel actively participated in the testing procedure and the consideration of utility theory, the subordinates in the group did likewise. Conversely, in one group, it was felt that the others were cautious of the entire theory and test because the senior member of the group reacted rather warily. For this reason, the extension of this work and the implementation of utility theory in the company should unquestionably start at the top level of management. Fortunately, it was observed that the top management decision makers were much more conscious of the need of better measures of value, and consequently more receptive to utility theory.

It was observed in one group that existing corporate policies were apparently the cause of the biases indicated by the participants' responses. The particular instance involved an existing policy of not drilling in Kansas. As a result, the responses given by the respondents of this group for proposals in Kansas were strongly biased. The bias was reflected by their choices of very high indifference points for the Kansas proposals. This observation suggests that the particular shapes of the utility curves may in some cases be reflecting corporate policies rather than individual preferences.

In the presentation of utility theory it was sometimes observed that the participants were judging utility theory as being a criterion to tell them how to make a drilling investment decision. In the discussion of utility theory it was emphasized that the theory is not prescriptive - but merely a convenient means of describing one's preferences. However, if the reactions observed in this research were representative, then the training of the decision makers on the use of utility theory must emphasize this point. To keep utility theory in the proper perspective in the decision process, the decision maker must recognize that expected utility does not tell him <u>how</u> to make a decision; but rather is a statement of his basic preferences for the monetary outcomes involved in the decision alternatives. Use of expected utility as a decision criterion is therefore a means of systematically accounting for biases affecting the decision maker's preferences. No other decision criterion has this inherent advantage.

CHAPTER IV

APPLICATION AND CONCLUSIONS

The results of the testing procedure discussed in the preceding chapter suggest the feasibility of using utility theory in drilling decisions. A few additional comments regarding use of utility as a decision criterion are, therefore, in order. Utility theory appears to offer the following advantages as a measure of value in drilling investment decisions:

1) It systematically relates bias caused by risk preferences, asset position, and corporate goals to monetary outcomes.

2) It is simple to use and its complete acceptance would provide the basis for more consistent drilling decisions.

3) Expected utility is a suitable capital budgeting ranking criterion - i.e. select drilling proposals in order of descending expected utility.

4) Top management decision policies could be conveniently delegated to lower management levels in the form of a decision curve.

5) Its use requires no re-investment assumption (as in discounted rate of return). The establishing of "minimum" returns-on-investment and/or payouts are eliminated.

To gain these apparent benefits would require the transition from the "standard" measures of value now in use to a totally new concept. If the technique of expected monetary value was in widespread use for drilling investment decisions the transition would be fairly simple. However, it was observed that none of the companies which participated were using mathematical expectation as a formal measure of value in their decision processes. In fact, some of the participants were only vaguely familiar with expected value. The implementation of utility theory will therefore involve a considerable amount of education or training. For these reasons it is recognized that the transition will be difficult and perhaps time consuming, and will require complete support of management.

Some initial steps or suggestions to begin the transition are given in the following section. The formal conclusions and implications of this research are given in the second section. The final portion of the chapter outlines a tentative proposal of a new method of determining utility curves. This method would be based on use of actual decisions over a period of time, rather than a testing procedure such as discussed in this study.

Implementation of Utility as a Decision Criterion

To implement utility theory into actual decision situations will initially require the definition of a utility curve which the decision maker feels is entirely representative of his preferences. The first step would be to devise the test procedure. Use of a procedure such as developed in this study appears to be a suitable way of testing; however, certain changes would be in order. The drilling proposals should be taken from areas where the particular company is actively drilling. The investment range would then be adjusted accordingly. Possibly the company may wish to use a different discounting rate, and perhaps include the effects of federal taxation.

The decision group may also find it advantageous to be given more than 10 decisions so as to more completely define the curve. This would suggest a testing procedure which might be given in two or three separate sessions. Another alternative would proceed as follows:

> After each actual drilling decision in the daily course of affairs, the decision maker would consciously evaluate his indifference point for the decision which had just been made. For example, suppose a proposal had just been made for the drilling of a $50,000 well with an estimated 100,000 barrels reserves and a risk factor of 0.60. Further suppose the decision maker decided to drill the well. He would then take a few moments to define the amount of reserves (or profitability) below which he would <u>not</u> have drilled - such as 70,000 barrels. If he had rejected the proposal he would then define the amount of reserves which would have been necessary for him to drill - such as 150,000 barrels. This indifference point would represent one test decision (but using an actual decision) and one point for the construction of his utility curve. This process would then be continued until sufficient data had been generated to construct the curve.

It is quite probable that even if use of expected utility as a decision criterion was initiated, the decision maker would continue to use some of his "standard" measures of value for a period of time. During this transition period expected utility would represent another "economic yardstick" in conjunction with rate of return, return-on-investment, etc. A drilling proposal might be presented as follows:

> "This well is expected to yield an ROI of ______ and payout in ______ months. The expected utility of the decision to drill is _________, whereas the expected utility of the alternative of farming out is only ________."

During the initial use of utility theory it is visualized that perhaps one person on the professional staff would over-see its application. This person would have to be totally conversant with utility theory, as well as being in a fairly responsible position with respect to the decision processes. The complete rapport between the individual and the decision maker would be essential until confidence in the theory is established.

A final comment is in order regarding the relationship between the value phase of the decision and the analysis of risk. It was stated in Chapter II that the number of outcomes that can be evaluated in the expected utility computation is unlimited. The example given in Table 3 (p. 29) contained only five possible outcomes ranging from a dry hole to reserves of 5 BCF. In the last several years methods of risk analysis have been developed that represent the outcomes from a particular decision as a continuous distribution (13). These techniques have been applied to the problem of risk analysis for drilling proposals as well (14). A description of risk in this manner offers the advantage of relating a probability with all possible values of ultimate profitability which might occur. Can utility theory be used as a measure of value when the outcomes are expressed as a distribution rather than specific profitabilities? The answer is yes and the following example briefly outlines a technique.

Suppose that several variables have been defined as affecting ultimate profitability, such as net pay, structural position, well costs, etc. Each variable is, in itself, probabilistic in nature. That is, the net pay could be 15 feet, but it might be 14 feet, or 3 feet, etc. instead. After making judgments as to the range and distribution of each variable, Reference 14 illustrates how these distributions are combined into a single distribution of ultimate discounted net profit. This distribution, when plotted on a cumulative basis might appear as in Figure 7. Now that the risk has been assessed, a measure of value of the decision alternatives must be determined. This is accomplished by dividing the profitability distribution into a series of intervals. One such interval having a width of $50,000 is shown. The midpoint of

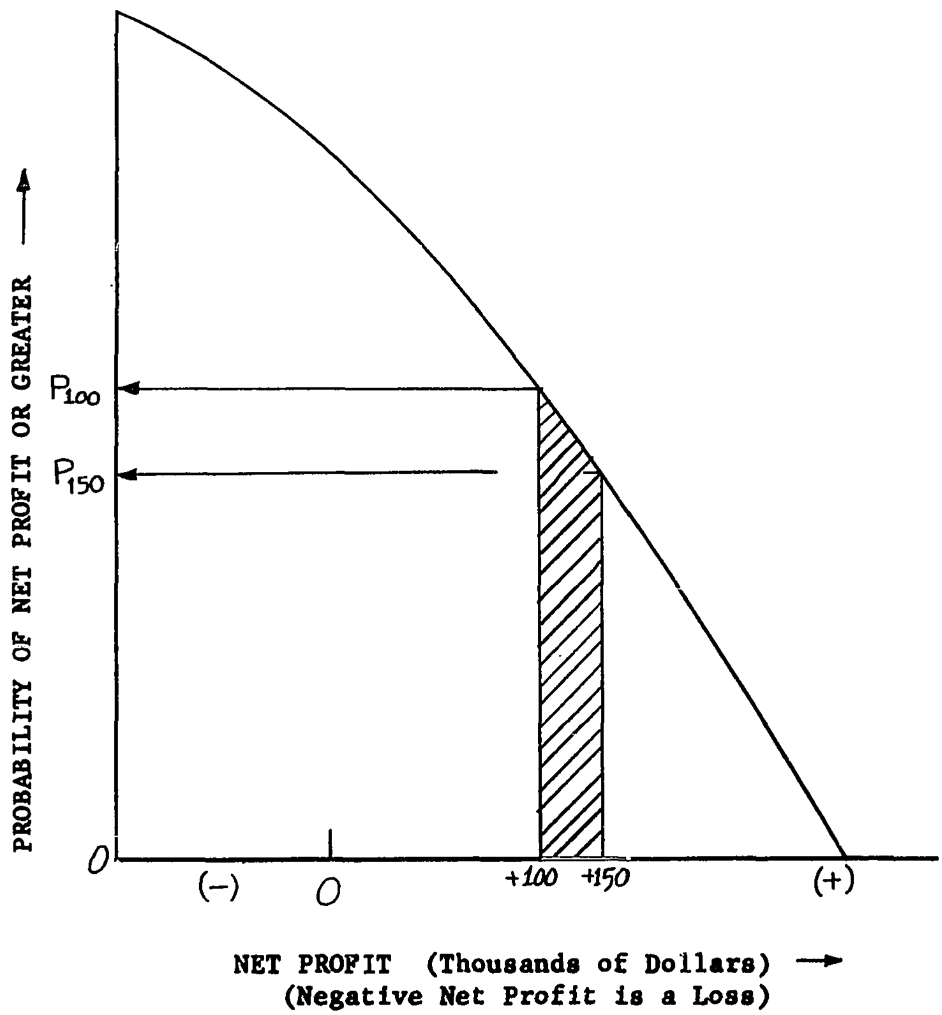


FIGURE 7 - Ultimate profitability as a function of probability for hypothetical drilling proposal

the interval ($125,000) is used to enter the decision maker's utility curve to determine his utility for that amount of net profit. The probability that a profit between $100,000 and $150,000 will occur is simply (P_{100} - P_{150}). The product of the probability and utility is obtained and algebraically summed with similar products for the remaining intervals to yield the expected utility of the alternative "drill". The intervals chosen do not have to be of equal size. The profitability distributions of other decision alternatives such as farm out, penalty clause, etc. are treated in a similar manner.

Conclusions and Implications of This Research

The applicability of this test procedure must ultimately be judged after the utility curve so constructed has been used in, or compared with "real-world" decisions. This might be accomplished by comparing the decisions dictated by expected utility computations with those made by management using present decision criteria over a period of time. Such a comparison would have to be done by company personnel and was obviously not within the scope of a university research program.

Several tentative conclusions, however, can be made from the results of the decision test procedures:

1) The testing procedure appears to be adequate in presenting the many factors which bias the decision maker considering a drilling investment proposal. The respondents had no particular trouble in understanding the testing technique.

2) Various statements made by the participants before, during, and after the testing concerning their preferences were usually reflected in the shape of their utility curves.

The results stated by the first conclusion were expected. This was because actual drilling proposals were being presented in a manner familiar to the participants. The second conclusion implies that the decision test developed in this research is capable of reflecting stated biases or preferences of the decision maker.

While this decision test procedure was developed specifically for the purpose of constructing a utility curve, it may have other uses as well. Its use as a training aid in drilling decision making appears feasible. For example, one company that participated requested that the test be given to their engineering personnel that prepare the recommendations. From the results of their participation, an interesting comparison was evident between the preferences of the professional staff making drilling recommendations and the decision maker who decides on the recommendation. The utility curves of the engineers were generally indicative of a conservative regard for the taking of risk. The utility curves of the actual decision makers (in the same corporate level) on the other hand, indicated a much greater willingness for taking risk, particularly at higher profit levels. This of course illustrates the change in thinking which is required of members of a professional staff when changing over to management capacities. Thus, a testing procedure such as developed in this research appears to have use as a diagnostic, or training aid as well.

Another implication of this research is the question of the effect of time on the shape of the utility curve. Some participants stated they felt that they might give different responses if they took the test again at a different time. Others indicated that at different times during a year their utility curve might vary depending on the quantity of drilling funds available. This research program did not try to test a given group of decision makers twice, for two reasons. First, it was felt that an entirely different set of proposals would be required, which would double the already large amount of time required to prepare the drilling proposals. A second unknown factor was whether or not the participants would be willing to devote another two hours from their usually crowded schedules.

The second comment regarding the change in shape of the utility curve as the company's asset position fluctuates during a budget period is perhaps well taken. Both comments, in fact, suggest that testing be on a periodic basis. Until experience is gained in this regard the question of the dependence of time on the utility curve will have to remain unanswered. If corporate policies do, in fact, change considerably with respect to changes in amounts of budgeted drilling capital available the chance for inconsistent decision increases. If this is the case, a revision of funding practices may be preferable to a revision of decision policies.

At one time during a presentation of the decision test a participant stated that he did not think the test was complete. He commented:

> "I can state my indifference point for this example, but if I were given other information such as 'the lease is expiring in a month', or 'we have a strong development demand' - then I might have a different point of indifference between drilling or not drilling. Without information such as this the test does not seem realistic."

The implication of his comment is this - How comprehensive or complete should the ultimate decision criterion be? If one had the time and patience it <u>might</u> be possible to devise a measure of value which would account for every possible contingency that might arise in a drilling decision. In the writer's opinion such a criterion, even if possible, would be so complicated and cumbersome to use that it would be of doubtful practical value. As stated at the outset of this study, it is desirable to account for biases caused by risk preferences, asset position, and corporate goals because these factors are present in every decision. On the other hand, the contingencies such as development demands, etc. occur only occasionally. The only logical way to reply to his comment seems to be that expected utility should be the decision criterion, subject to any contingencies which are pertinent in special instances. A formal decision criterion can minimize the amount of judgment required but does not, and can not, eliminate the need for said judgment for specific decisions.

As with most research, this work raises many new questions and fails to answer some of the old ones. It does, though, clearly show for the first time the degree to which certain biases enter into drilling investment decisions. Utility theory is a convenient way to treat these biases in a systematic manner, and appears to be worthy of incorporation into an organization's decision making process.

An Alternative Method to Determine Utility Curves

While this particular testing procedure appears to be more realistic and representative than those developed previously, it is perhaps not the ultimate way of determining a decision maker's utility curve. For no matter how realistic the test decisions are, they are still only part of a test, with absolutely no money being gained or lost by the decisions that are made. A better method might be to construct the curve from "real-world" decisions that are made over a period of time. The obvious problem is that actual decisions are made in terms of drill or farm out, rather than definition of the indifference point between each alternative. Briefly outlined below is an alternative approach which might permit construction of the utility curve from the actual decisions made over a period of time. This is a tentative proposal unconfirmed by the formal testing performed in this research.

Suppose a drilling proposal having the following payoffs were accepted.

Risk Factor: 0.60
Loss if a dry hole: $50,000
Net Profit if a producer: $150,000

Further suppose we arbitrarily assign a utility of -10 to the $50,000 loss and a utility of 0 to the alternative of no action (zero net profit). Since the decision maker accepted the prospect, and assuming that he acted in accordance with the utility theory axioms, then we are able to conclude that his utility for the gamble exceeded his utility for taking no action. That is:

$$0.4 \times U(-\$50{,}000) + 0.6 \times U(+\$150{,}000) > U(\$0)$$

or

$$0.4 \times (-10) + 0.6 \times U(+\$150{,}000) > 0.$$

This implies that his utility for a net profit of $150,000 must be greater than 6.67.

Now suppose that two days later he rejects a drilling proposal with the following payoffs:

Loss if a dry hole: $50,000
Net profit if a producer: $200,000
Risk Factor: 0.40

Since this was rejected his utility for the gamble must be less than that of no action. That is:

$$0.6 \times U(-\$50{,}000) + 0.4 \times U(+\$200{,}000) < U(\$0)$$

or

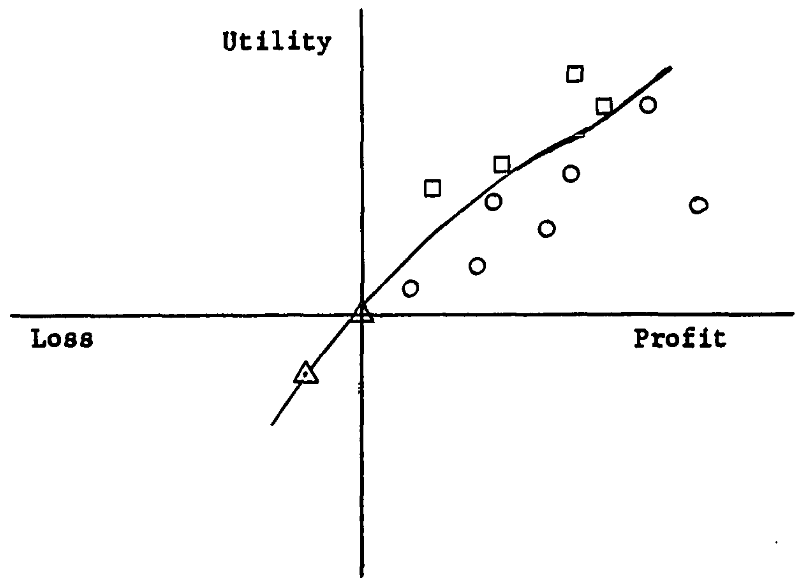
$$0.6 \times (-10) + 0.4 \times U(+\$200{,}000) < 0.$$

This implies that his utility for a net profit of $200,000 is less than 15.0.

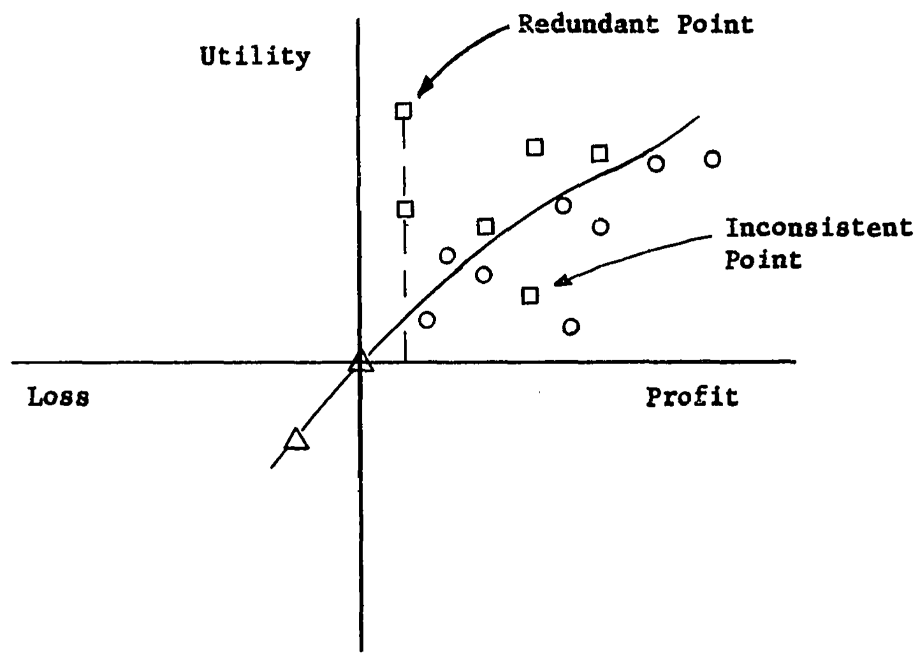
We now know that his utility curve is above 6.67 for a profit of $150,000 but below 15.0 for a profit of $200,000. As successive decisions are made additional constraints on the location of the curve at various profits are obtained. To graphically describe the procedure suppose that circles are used to plot the points such as 6.67 (with the meaning that the curve lies above this point) and squares are used to plot points computed from rejections (with the meaning that the curve lies below this point). After a sufficient number of decisions had been analyzed in this manner, the utility curve could be constructed as that line which separates the circles from the squares (subject of course to the constraint that the line be monotonically increasing with increasing profit). This technique is illustrated in the upper portion of Figure 8.

Conceivably some of the points would be redundant or inconsistent, as illustrated in the lower portion of Figure 8. For example, suppose from one decision we conclude that his utility for a $100,000 net profit is less than 30, and from another decision that his utility for a $100,000 net profit is less than 15. This might occur if decisions of different investment levels and probabilities, but equal payoffs were compared; and does not imply an inconsistent decision. The latter point would then control and the former would be redundant. The inconsistent decisions would have to be neglected and/or re-examined to determine the influence of extraneous factors such as lease expiration, royalty owner demands, etc. on the decision.

This particular scheme would only be satisfactory if every loss for a dry hole were equal, such as $50,000. This is because the utility for the loss must initially be assumed. Obviously this condition would not be totally applicable for companies which are simultaneously drilling in areas of widely divergent well costs. It might be quite possible, however, that a large portion of the wells are being drilled in an area where the dry hole costs vary only slightly. If this were the case, a



a.) Case where decision maker was completely transitive



b.) Case where decision maker has made several inconsistent decisions

FIGURE 8 - An alternative method to construct utility curves
(△ Points arbitrarily selected)

negative utility could be assigned to this loss and decisions from these particular areas could be used to estimate the shape of the curve. Values from this curve could then be used to extend the range of the curve, in the manner stated in Chapter III.

An alternative would be to construct a utility curve initially from a test procedure. Then the shape of the curve would be modified in the manner described using actual decisions (presuming the decision maker is not using expected utility as a formal criterion).

A technique such as described in this section would have the advantage of using actual decisions for the construction of the utility curves rather than a testing procedure of some sort. If the parameter for the utility curve is discounted net profits obviously these profits would have to be presented to the decision maker, rather than undiscounted net profit. Its use would also require the statement of risk to be a single probability estimate such as was given in the example decisions of this section.

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APPENDIX

This section presents the tabulated responses of each decision maker that participated in the test procedure, together with the utility curves constructed from these responses. The experimental data are arranged in four groups, such as Group A, Group B, etc. Each group represents one company. The individual participants are designated by numbers with the group letter prefix. The composite, or average utility curve (described in Chapter III) is also given for each group.

At the beginning of each group's responses and individual utility curves is a brief description of the particular corporate level of the company. As a general rule most oil companies are structured as follows: General of Head office, Division of Regional offices, and District or Area offices. Normally drilling decisions are not made at levels below the District or Area. To describe the particular levels of each group involved in the decision test, the following convention will be used:

Corporate Designation	
First Level	Decision makers in the General or Head office
Second Level	Decision makers in Division or Regional offices
Third Level	Decision makers in District or Area operating offices.

This convention is adopted to preclude any specific reference to the names of the operating offices of the various companies. At the end of each group's responses and utility curves is a list of various comments and observations that are pertinent to the particular group or individual decision makers of the group.

The method of computation of the utility curves was outlined in Chapter III and will not be repeated here. All the utility curves are plotted on the same scale to facilitate comparisons of the decision preferences of the respondents. In a few instances there are data points which exceed the range of the scales chosen, and these are marked accordingly. In most cases these points represented inconsistent decisions and were not used for the plotting of the utility curves.

GROUP A

The four participants from this company were first level management decision makers. The company is one of the largest major oil companies, and operates a substantial amount of production in the Oklahoma and Kansas areas covered by the decision test. The participants were members of a larger decision group of the corporate level. The others in the group (including the President and Executive Vice-President) did not participate due to previous business commitments on the testing date.

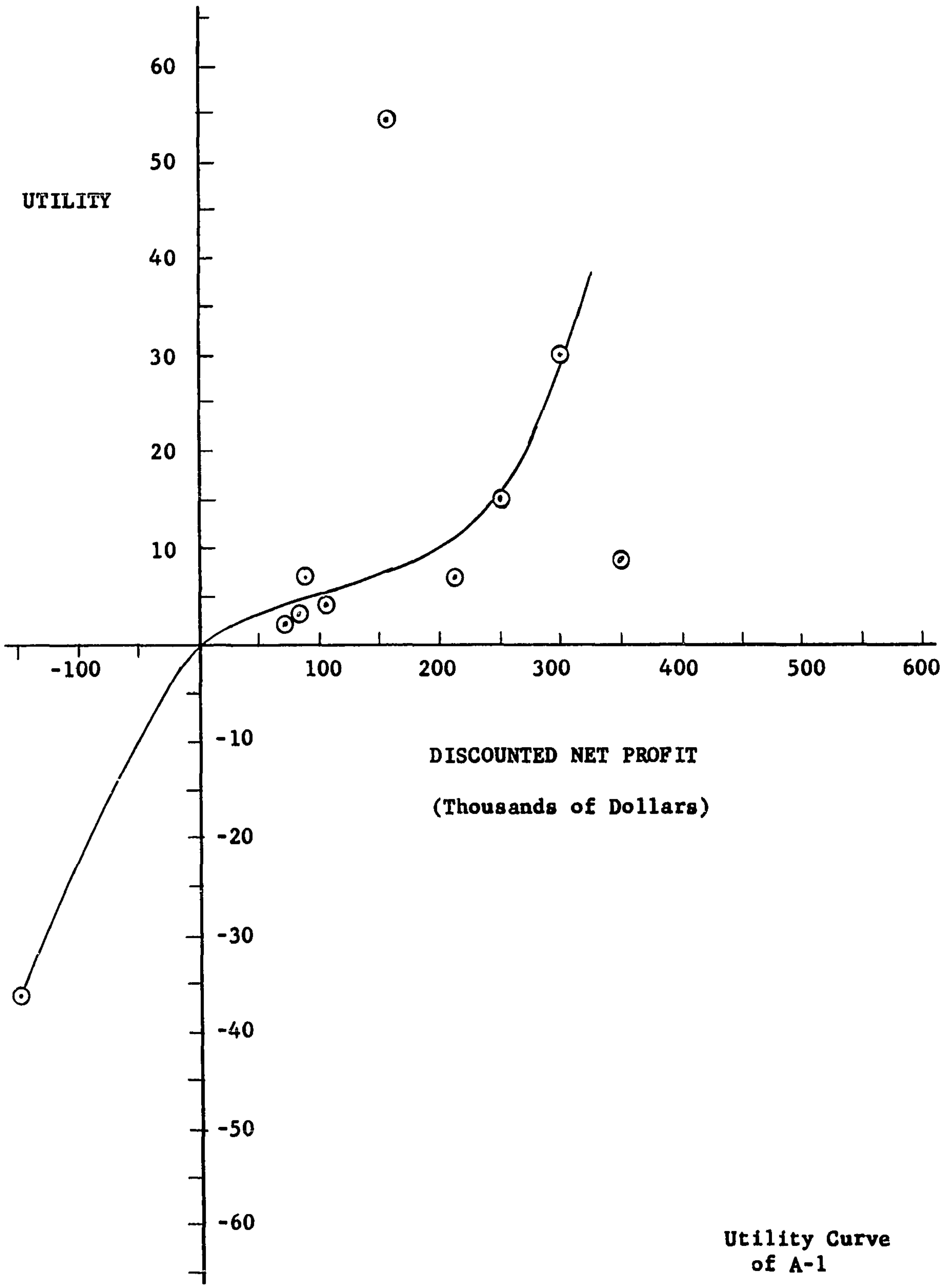
Table A contains the responses that were given by the four participants in the order in which the decisions were presented.

TABLE A

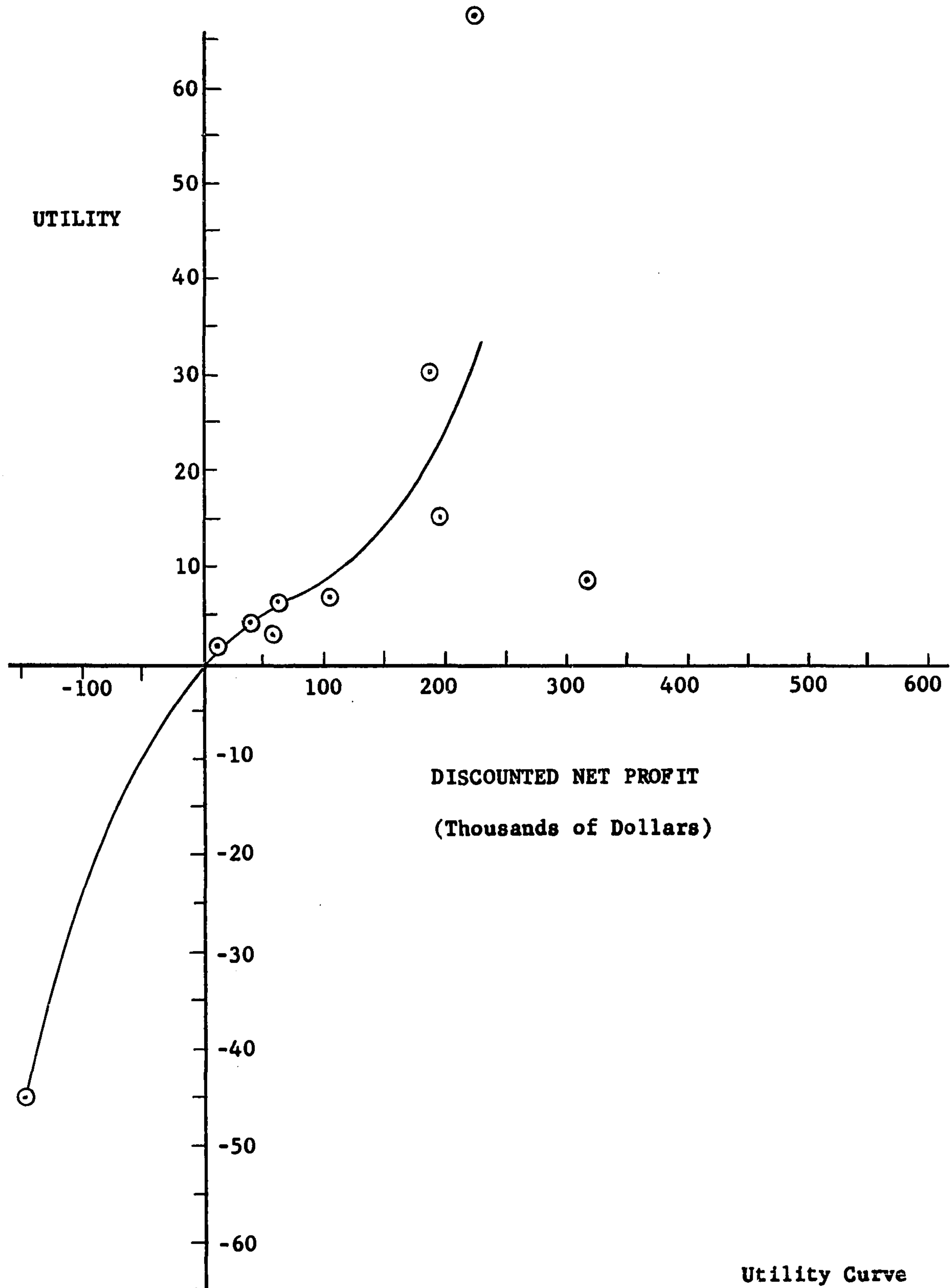
DECISION RESPONSES OF GROUP A

Proposal No.	Investment		Risk Factor	Indifference Points, Disc. Net Profit				
	Producer	Dry Hole		A-1	A-2	A-3	A-4	Composite
3	$ 50,000	$ 30,000	0.70	$ 70,000	$ 8,000	$ 65,000	$ 74,000	$ 54,000
4	70,000	50,000	0.60	85,000	105,000	105,000	135,000	107,000
5	55,000	30,000	0.55	104,000	43,000	75,000	92,000	79,000
8	80,000	50,000	0.60	216,000	64,000	115,000	115,000	128,000
1	70,000	50,000	0.25	300,000	185,000	245,000	175,000	226,000
6	80,000	50,000	0.40	250,000	198,000	155,000	95,000	175,000
10	150,000	90,000	0.70	350,000	320,000	500,000	130,000	325,000
7	185,000	150,000	0.40	155,000	226,000	410,000	300,000	273,000
2	40,000	30,000	0.60	80,000	60,000	60,000	76,000	69,000
9	200,000	150,000	0.60	285,000	215,000	300,000	165,000	241,000

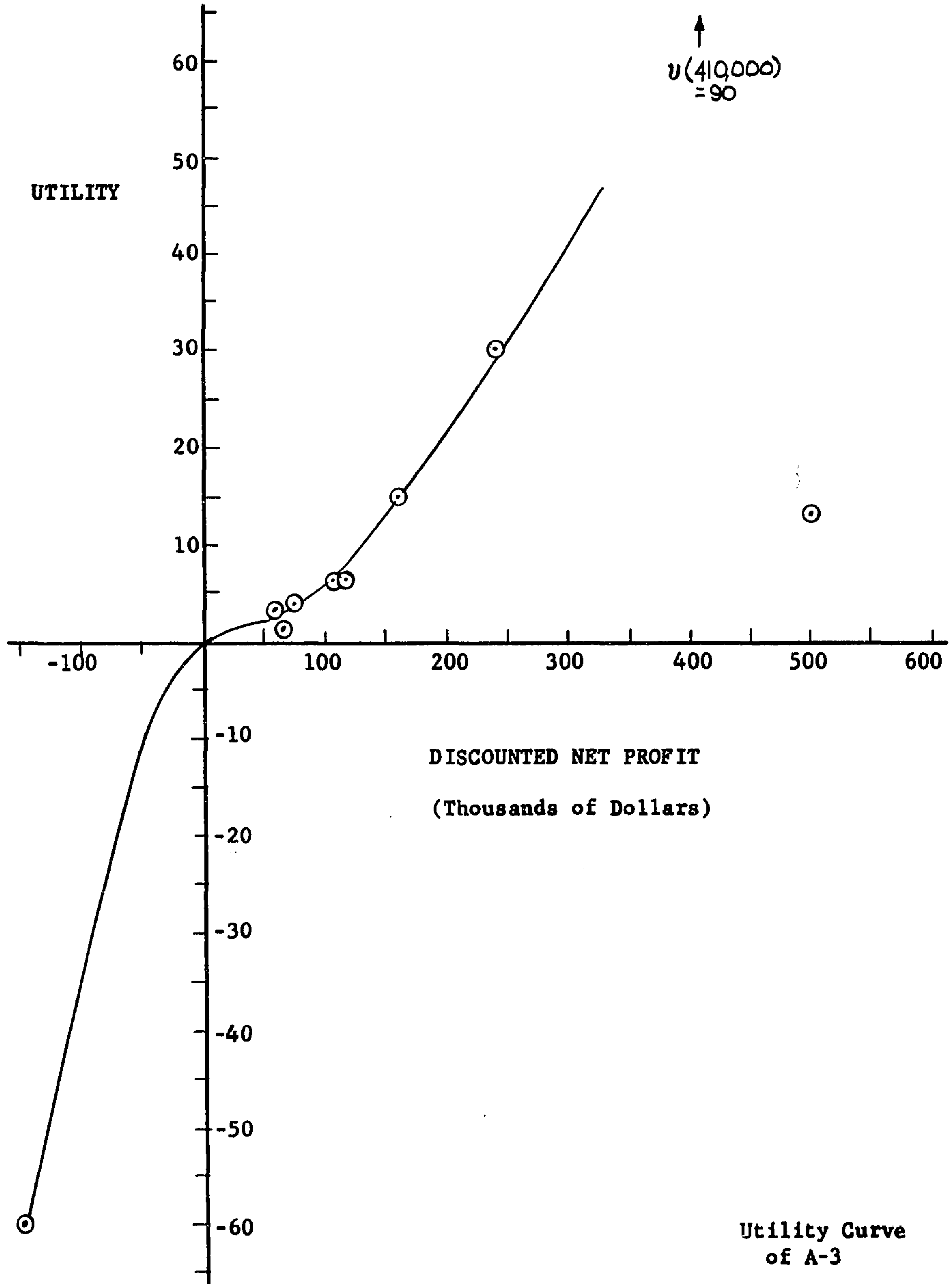
(Risk factor is the reliability of interpretation)



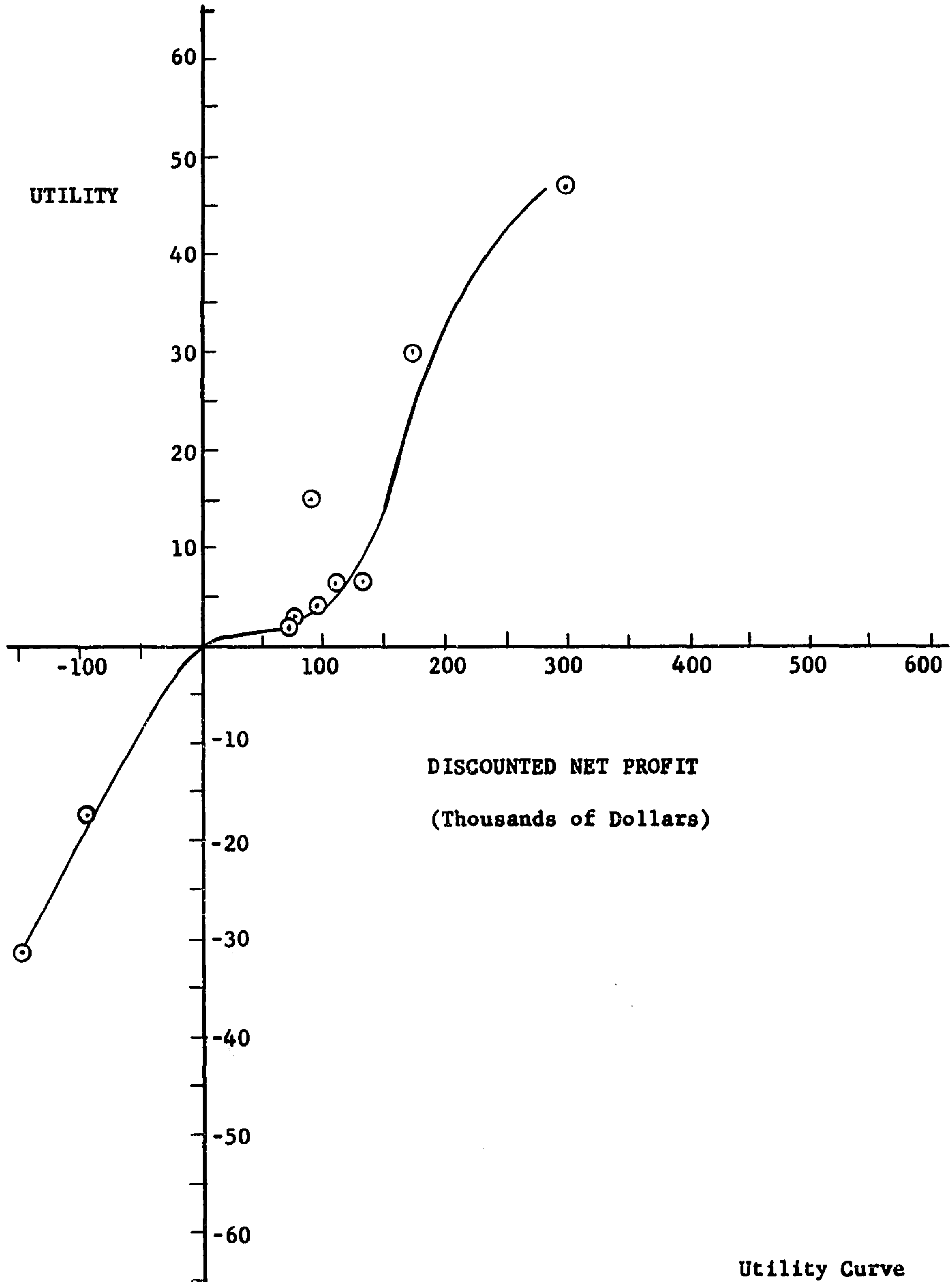
Utility Curve
of A-1



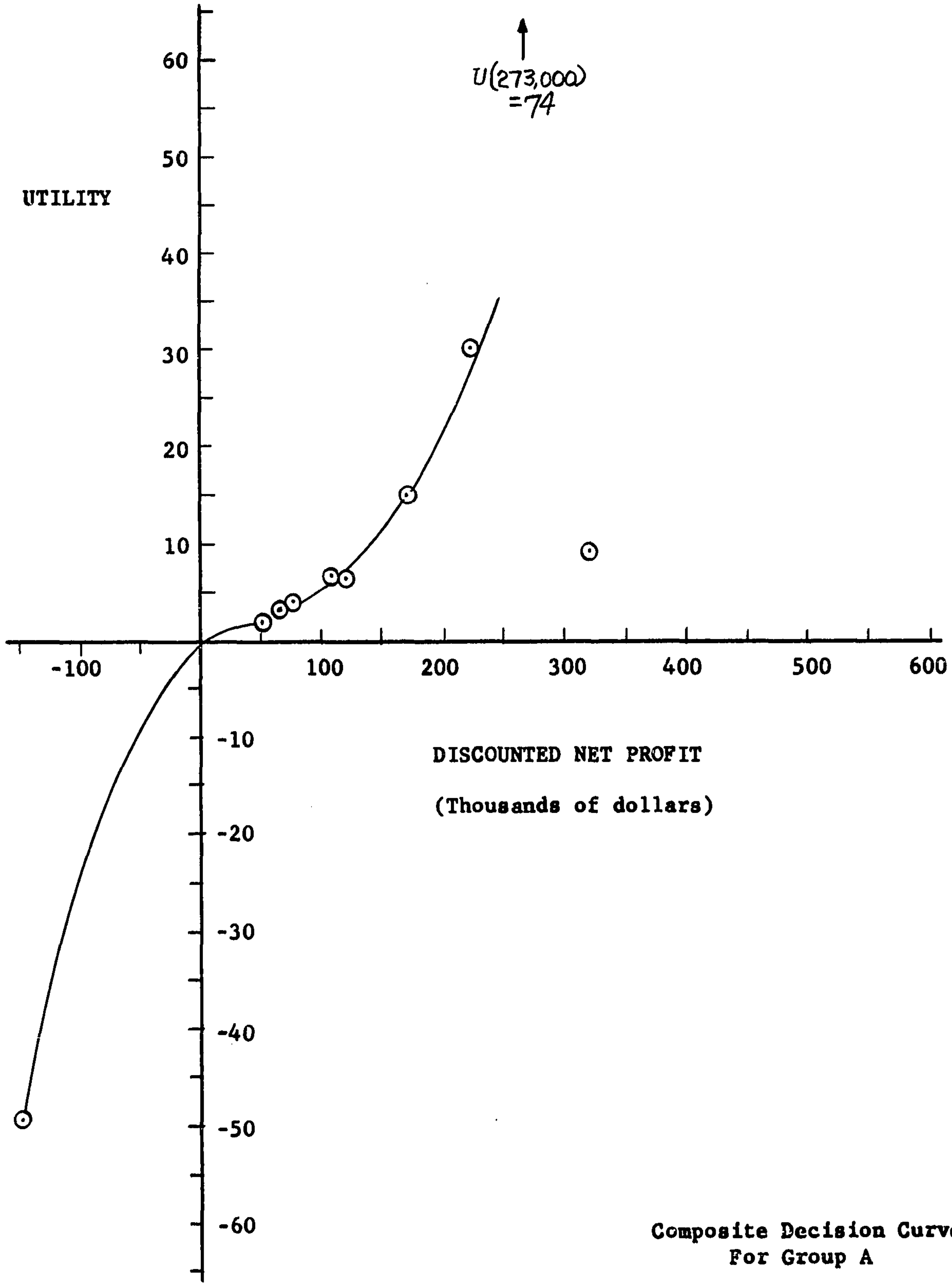
Utility Curve
of A-2



Utility Curve
of A-3



Utility Curve of A-4



Composite Decision Curve
For Group A

COMMENTS - GROUP A

1) Respondent A-1 stated during the testing that he did not care for the Oswego limestone production of Proposal Number 8. His indifference point ($216,000) was high with respect to his decision for Proposal 4 having the same risk and dry hole losses. His response for Proposal 7 indicated a strong preference for this type of production. His associated utility for the $155,000 minimum is much higher than his utility for this amount of profit determined from his other responses.

2) The point which falls below the utility curves of A-1, A-2, A-3, and the composite in the high profit range was the response given for Proposal 10. This proposal had a 3 year shut-in delay. Their responses suggest a preference for projects which will not defer future income to such an extent. On the other hand, A-4 appeared to not have quite as strong a feeling regarding the shut-in delay. It was clearly stated in the presentation that the discounted net profit curve did reflect the deferred income.

3) Respondent A-2 had a stronger preference for prospects in the low profit ranges than did the others. Before the testing he asked how the shape of a utility curve would reflect a corporate policy of a mix of high return, expensive investments, and less expensive "bread and butter" type wells. During the testing when one of the less expensive, fast payout proposals was given he stated, "These are the kind of prospects I like". His utility curve reflects this stated preference.

GROUP B

The nine participants in this group were from a medium size integrated oil company. Seven of the participants were third level management personnel and two were second level decision makers. The test was given in the offices of the lower corporate level. The two other respondents were visiting in the office. The seven respondents represented all supervisory positions and staff heads in the organization of that particular office. The company operates production in both Oklahoma and Kansas, however, they currently do very little development or exploratory drilling in Kansas.

Table B contains the responses of the nine participants in the order in which the decision proposals were presented. Testing proceeded somewhat slower than had been anticipated, and because of time limitations only seven drilling proposals were presented.

TABLE B

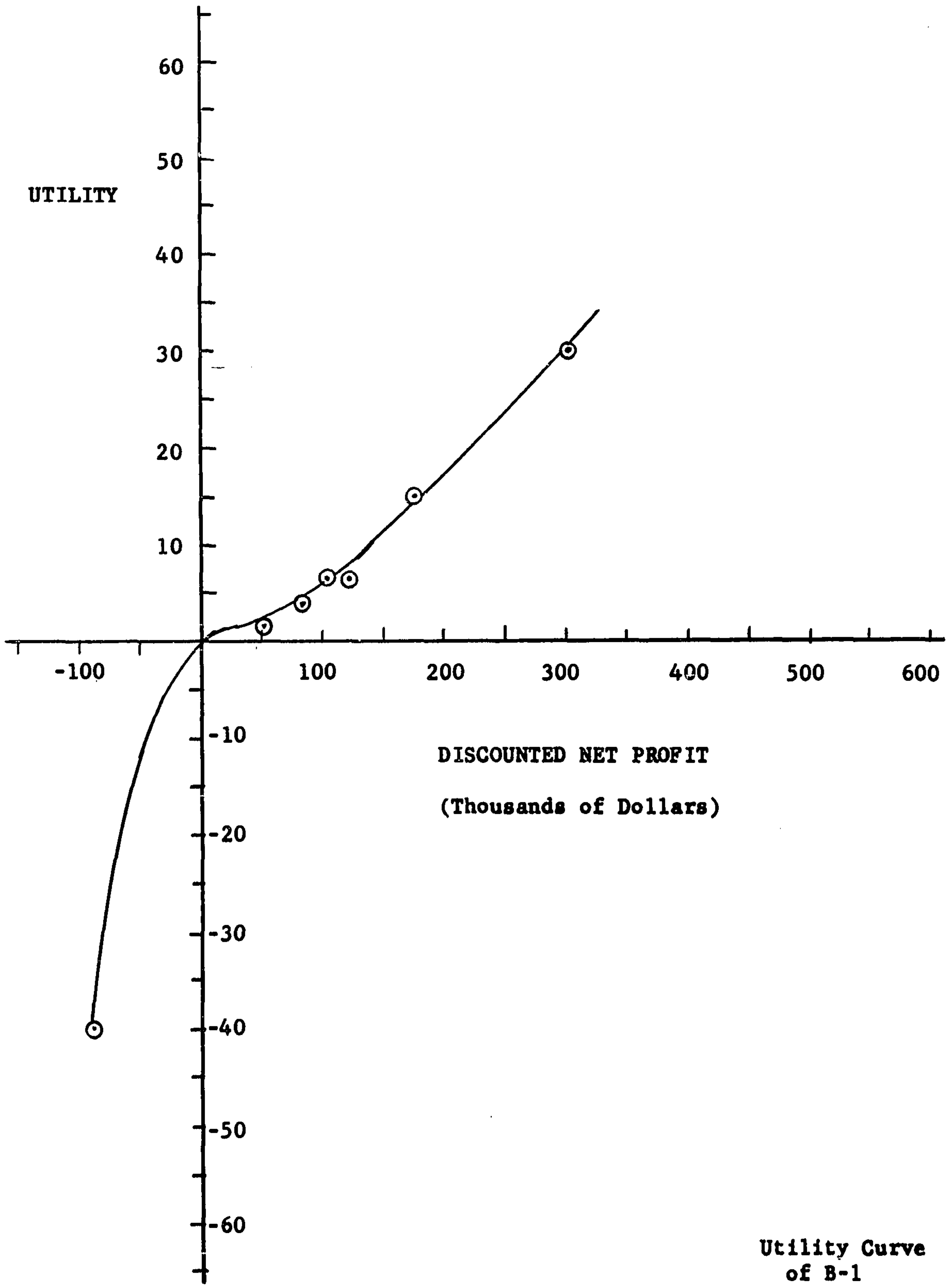
DECISION RESPONSES OF GROUP B

Proposal No.	Investment		Risk Factor	Indifference Points, Disc. Net Profit				
	Producer	Dry Hole		B-1	B-2	B-3	B-4	B-5
3	$ 50,000	$ 30,000	0.70	$ 50,000	$ 58,000	$ 98,000	$176,000	$ 66,000
4	70,000	50,000	0.60	100,000	170,000	135,000	210,000	170,000
5	55,000	30,000	0.55	80,000	72,000	72,000	145,000	72,000
8	80,000	50,000	0.60	120,000	44,000	56,000	152,000	120,000
10	150,000	90,000	0.70	200,000	180,000	650,000	500,000	135,000
6	80,000	50,000	0.40	175,000	250,000	275,000	300,000	250,000
1	70,000	50,000	0.25	300,000	675,000	2,400,000	2,400,000	1,600,000

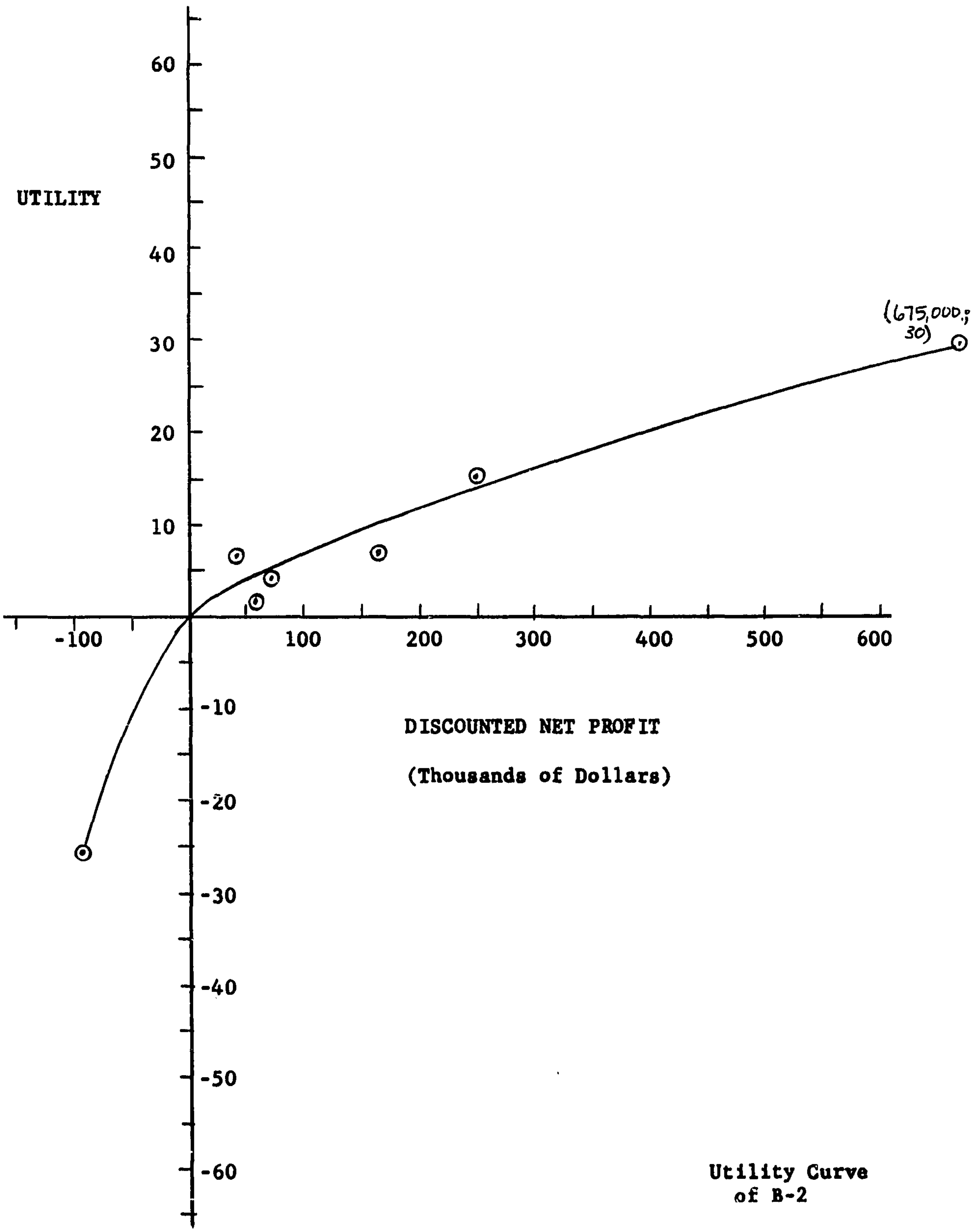
Table continued on following page

TABLE B - Continued

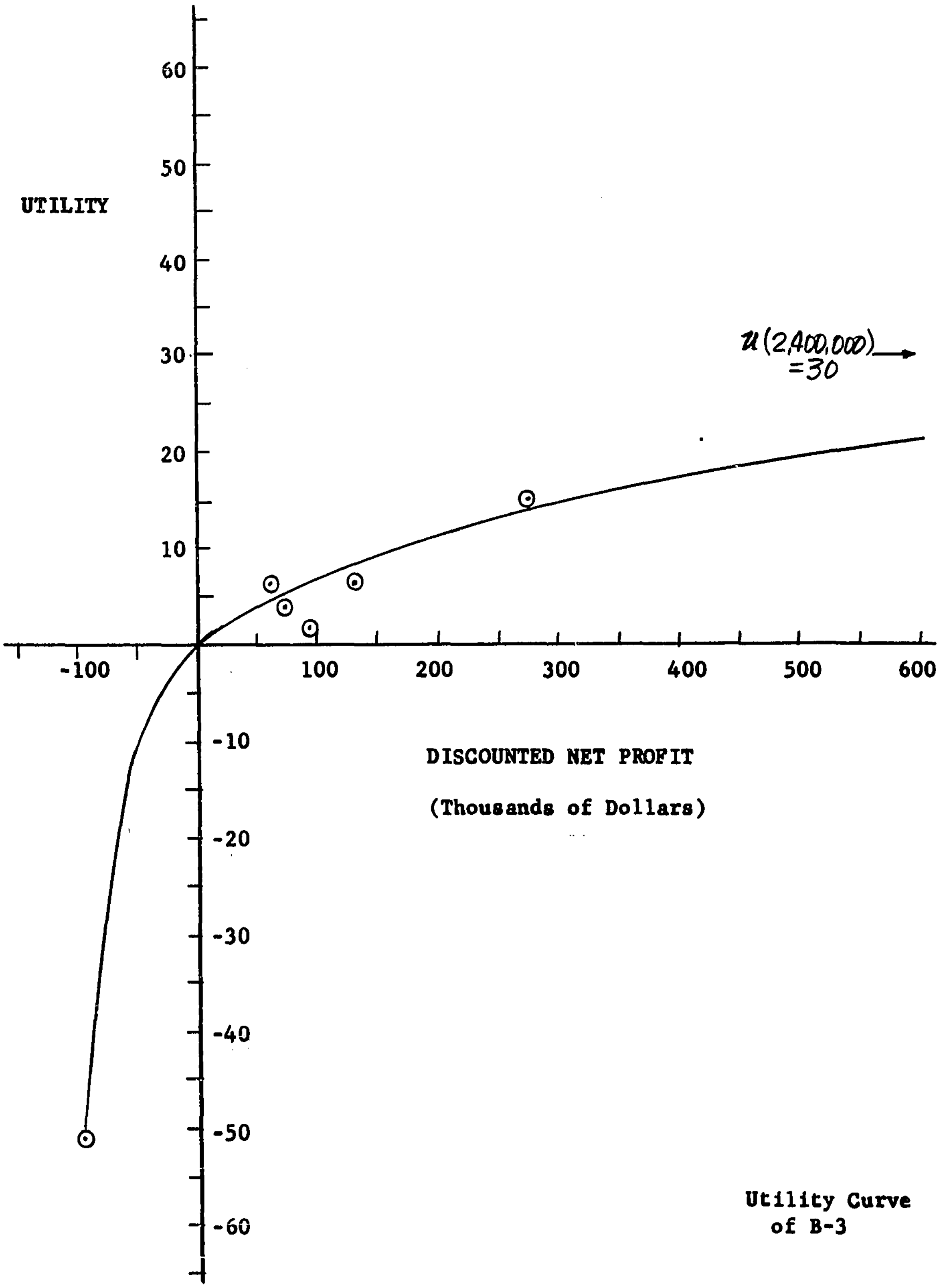
Proposal No.	Investment		Risk Factor	Indifference Points, Disc. Net Profit				
	Producer	Dry Hole		B-6	B-7	B-8	B-9	Composite
3	$ 50,000	$ 30,000	0.70	$ 74,000	$ 100,000	$ 82,000	$ 188,000	$ 99,000
4	70,000	50,000	0.60	170,000	300,000	600,000	420,000	253,000
5	55,000	30,000	0.55	85,000	125,000	473,000	65,000	132,000
8	80,000	50,000	0.60	86,000	90,000	240,000	86,000	110,000
10	150,000	90,000	0.70	235,000	300,000	320,000	900,000	380,000
6	80,000	50,000	0.40	200,000	375,000	200,000	600,000	292,000
1	70,000	50,000	0.25	700,000	2,400,000	298,000	2,000,000	1,419,000



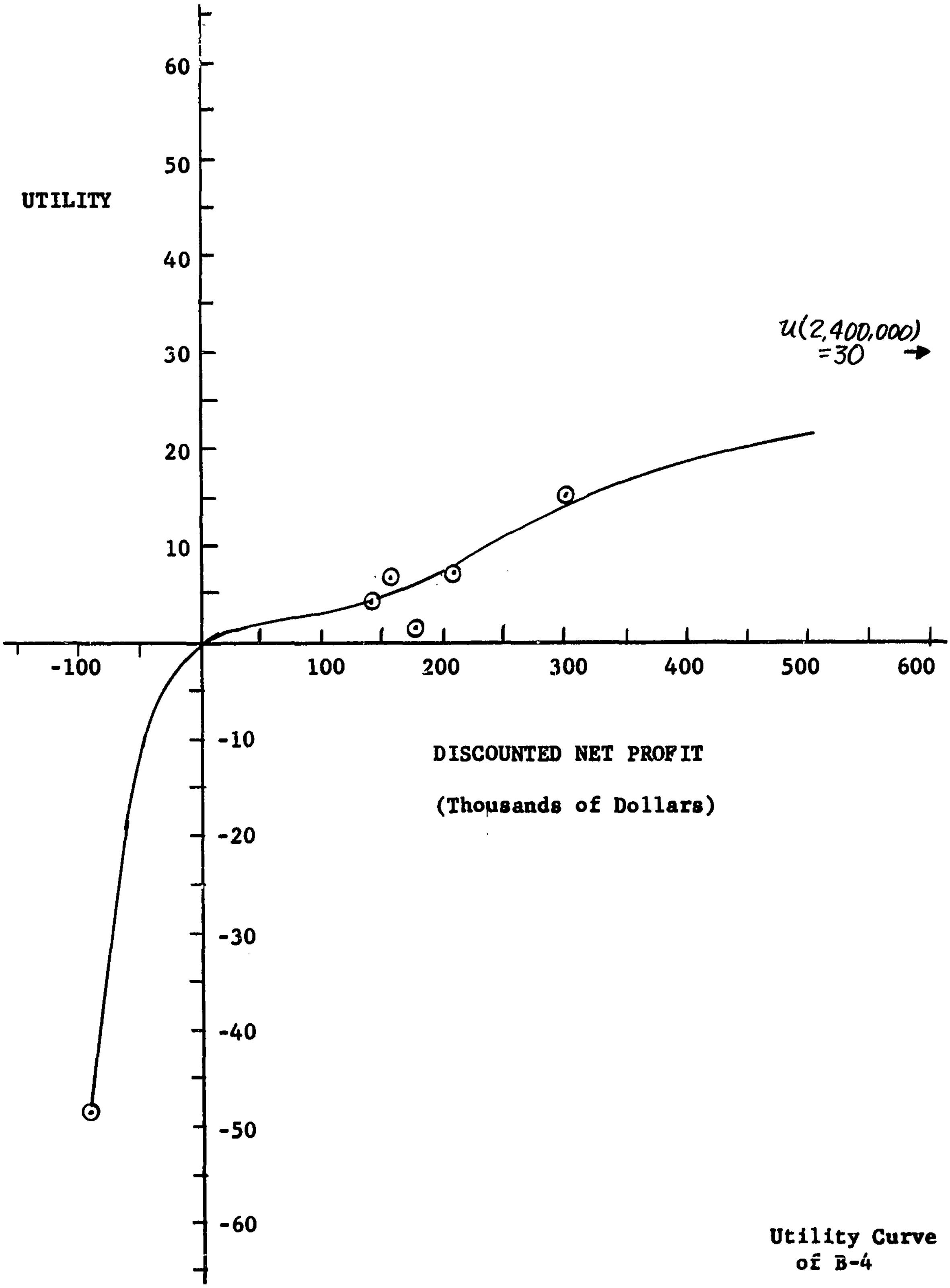
Utility Curve
of B-1



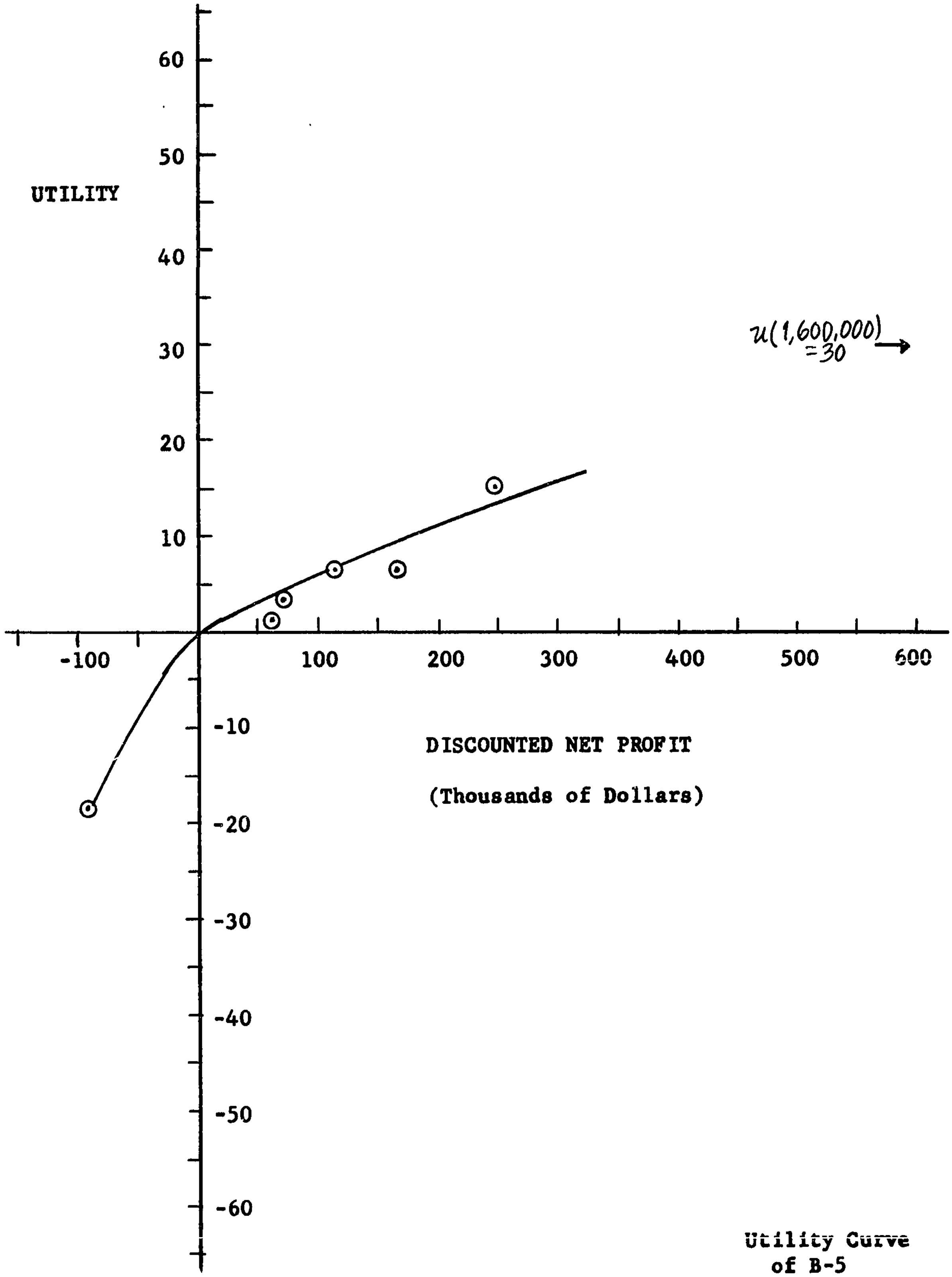
Utility Curve of B-2



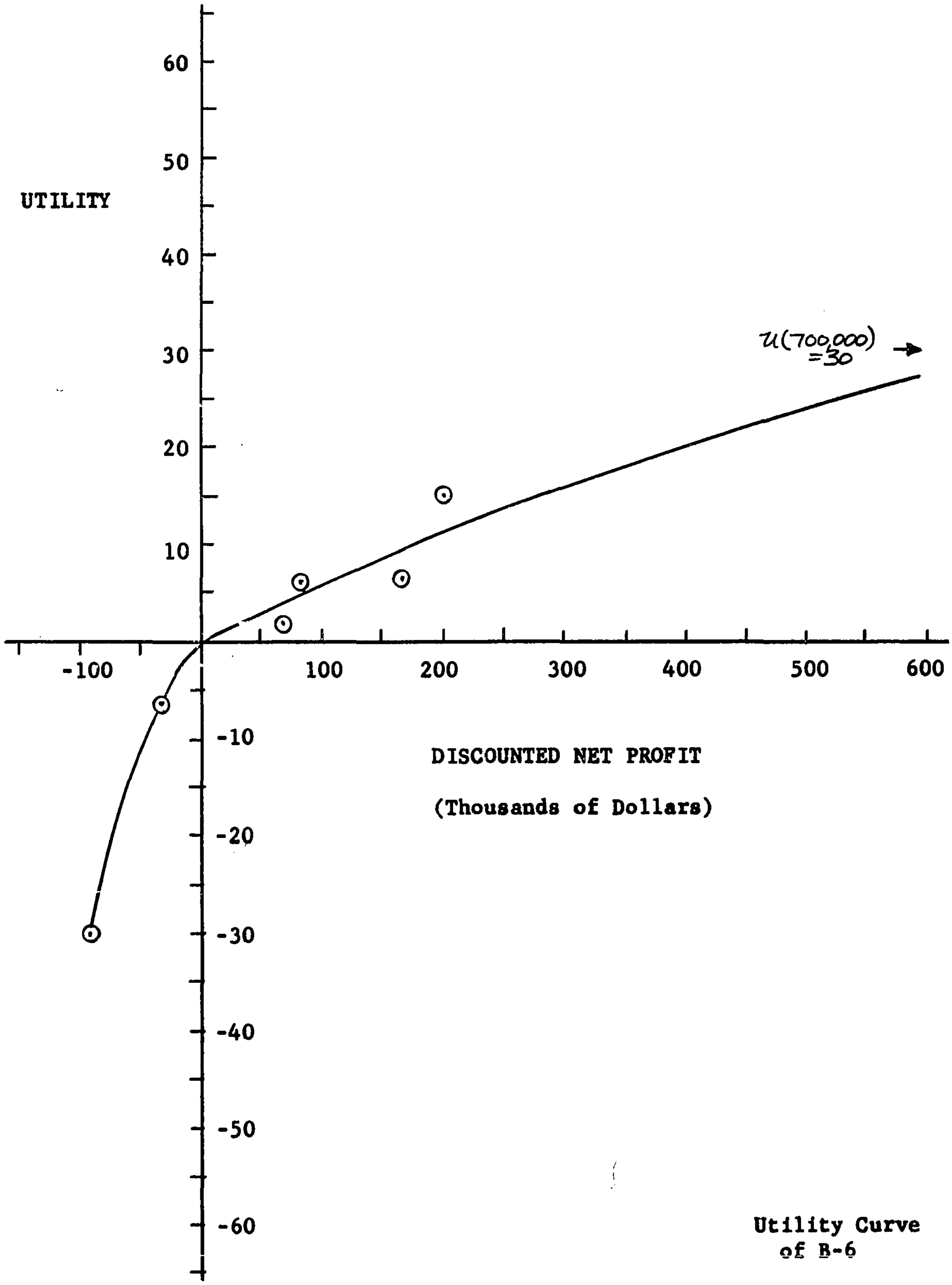
Utility Curve
of B-3



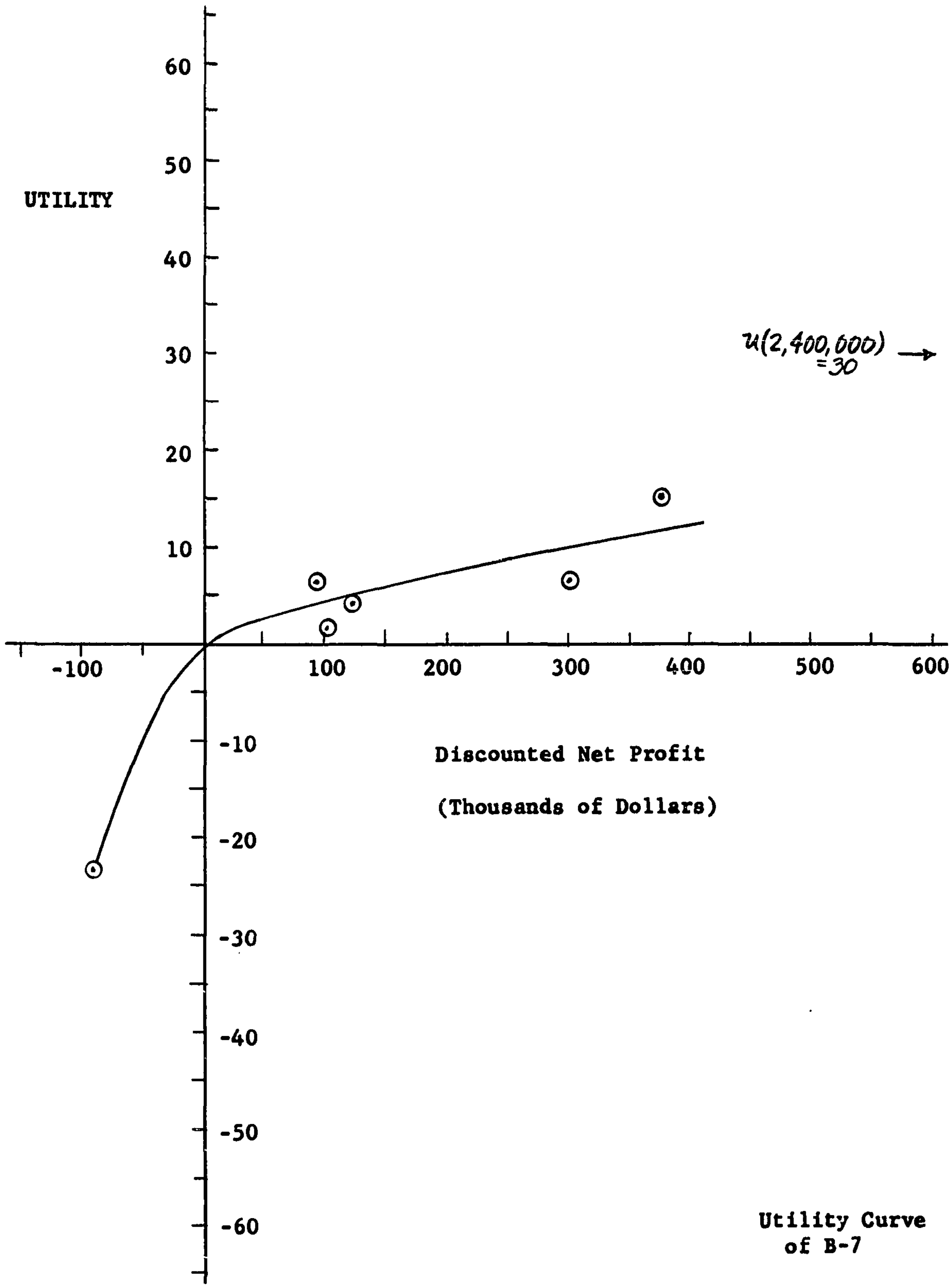
Utility Curve
of B-4



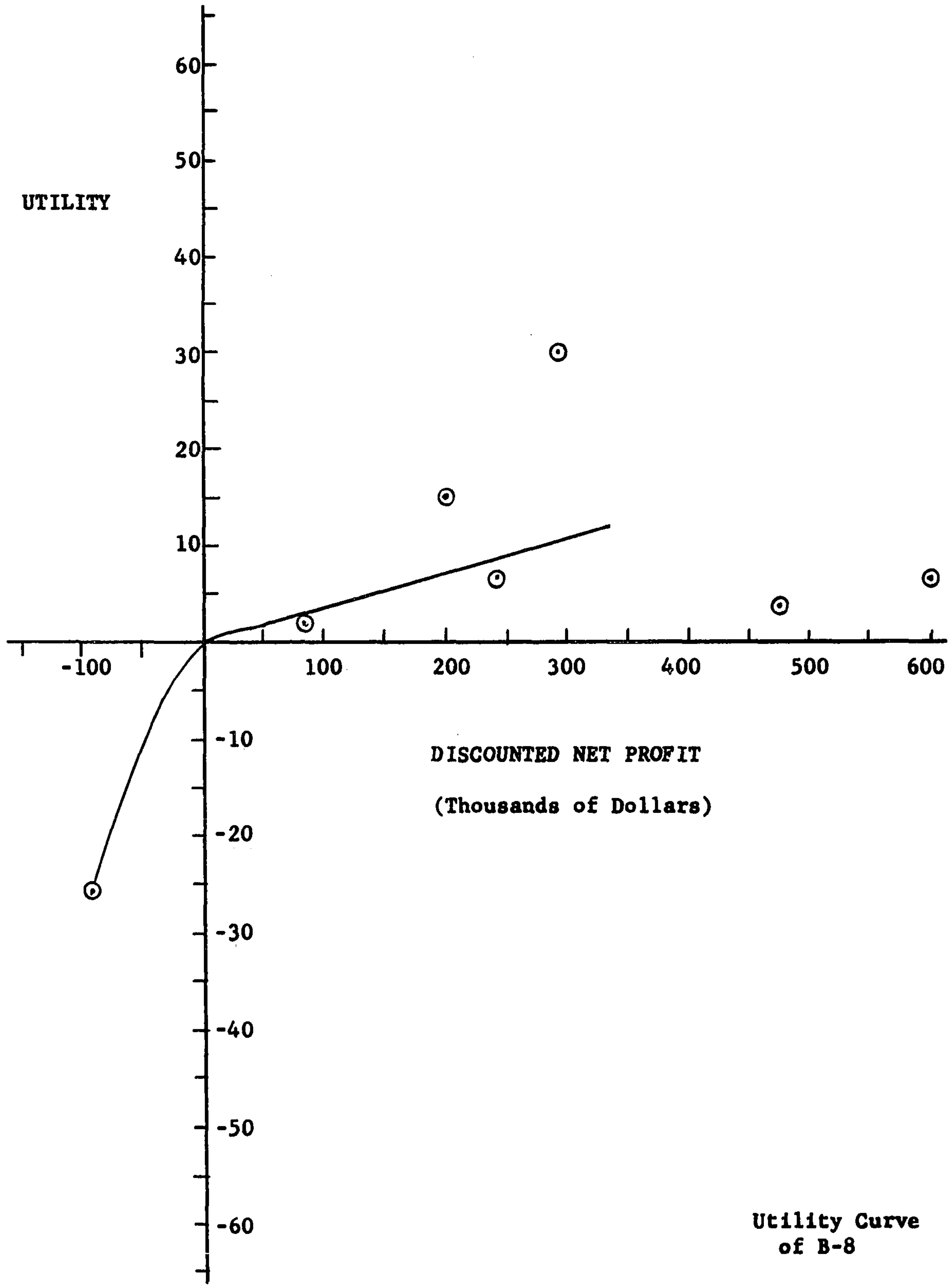
Utility Curve
of B-5



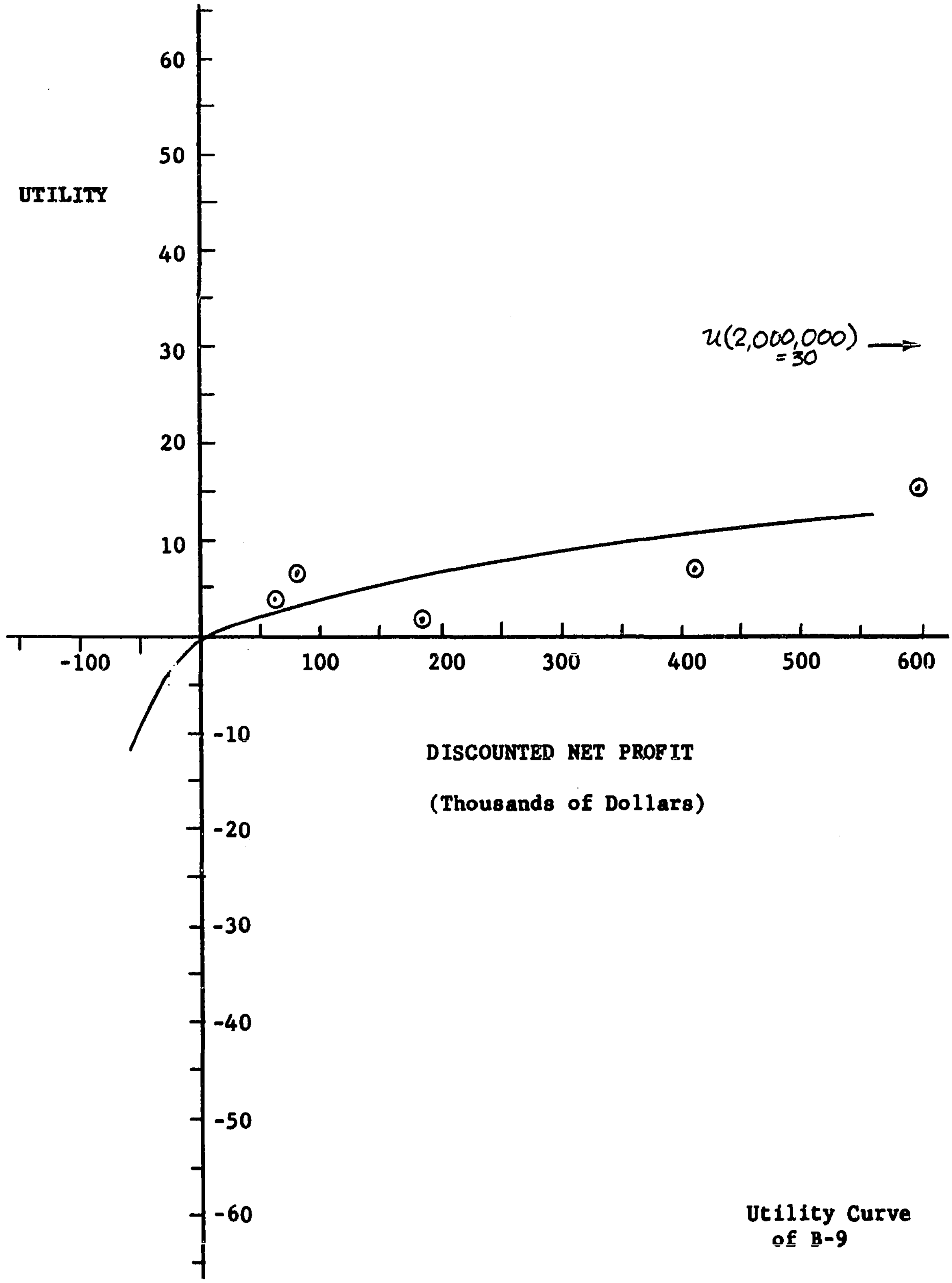
Utility Curve
of B-6



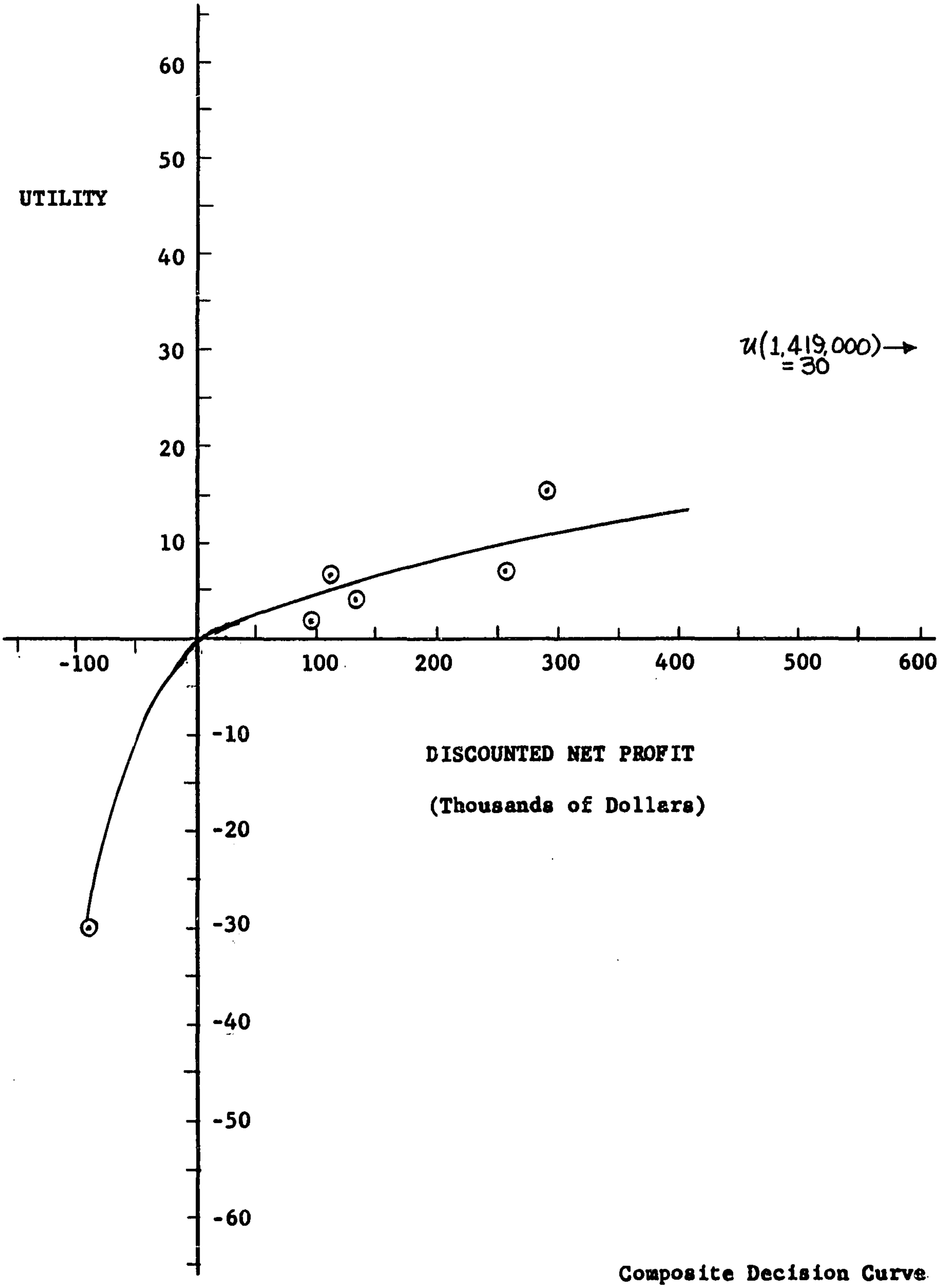
Utility Curve
of B-7



Utility Curve
of B-8



Utility Curve
of B-9



Composite Decision Curve
For Group B

COMMENTS - GROUP B

1) As a general statement this group of decision makers appear to be conservative in nature, as evidenced by the generally flat shape of their utility curves. The exception was B-1 whose utility curve was much steeper. This suggests that he would drill any of the prospects for a lower ultimate profitability.

2) Some of the respondents appeared to have some trouble with the particular testing procedure. This is displayed in the scattering of data points of the utility curve of B-8. He asked several questions which suggested a slight confusion about the format. Respondent B-9, after being presented two drilling proposals, stated he just did not understand the definition of the indifference point. The idea was explained for several minutes by the writer, as well as some of the other participants, but he did not indicate that the point was completely clarified in his mind.

3) Their responses to Proposal No. 1 should be noted. (This is a $70,000 exploratory well in southwestern Kansas.) While it was being presented, one of the two participants from the second level of management stated their company policy at the time did not favor exploratory drilling in Kansas. The participants were then asked to consider the prospect as if this policy were not in existence. After the prospect was presented there were numerous questions about it which suggested they were having trouble evaluating the proposal or else had a strong dislike for the proposal. One of the participants from the upper corporate level asked if he were permitted to put down a value as high as 3,000,000 barrels (a discounted net profit of $2,400,000).

He was advised that he could if he so desired. Apparently his question influenced the others in their responses, as two others put down the exact amount, and all but two stated at least one million barrels or more. As a matter of interest the net profit curves on the proposal sheet were plotted only up to 360,000 barrels of total ultimate field reserves. As a result of the high minimum set for this proposal nearly all the curves have a utility point at +30 which far exceeds the net profit scale. Their responses to this proposal suggest one or more of the following:

a) The corporate policy of not drilling in Kansas at the time biased their responses.

b) Some of the participants were influenced by the stated preference of one decision maker of only considering the drilling for a very large amount of reserves.

c) The company, as a general rule, does not particularly care to invest capital in exploratory drilling ventures.

4) A general feeling among some of the participants was stated after the testing that in their minds very few of the prospects presented appeared to be desirable drilling locations.

GROUP C

This group of participants were all in second level management positions of a large major oil company. The nine participants included all the management positions and staff department heads of the particular office. This office of the company operates production and an active drilling program in both Oklahoma and Kansas. All the respondents seemed familiar with the types of production and drilling problems presented in the test proposals.

Table C contains the responses that were given by the nine participants in the order in which the decisions were presented.

TABLE C

DECISION RESPONSES OF GROUP C

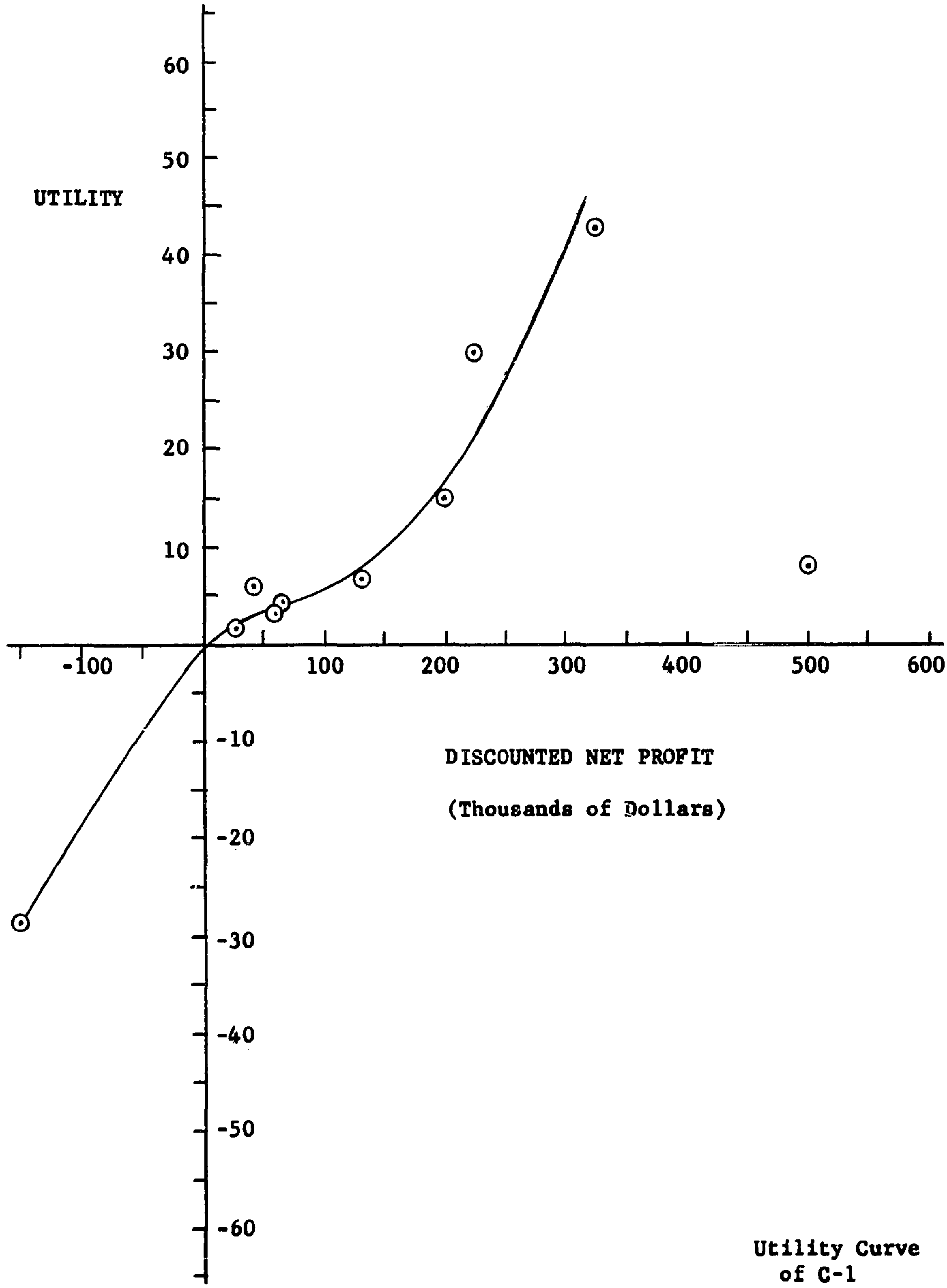
Proposal No.	Investment		Risk Factor	Indifference Points, Disc. Net Profit				
	Producer	Dry Hole		C-1	C-2	C-3	C-4	C-5
3	$ 50,000	$ 30,000	0.70	$ 30,000	$ 20,000	$ 66,000	$ 20,000	$ 53,000
4	70,000	50,000	0.60	135,000	135,000	105,000	105,000	120,000
10	150,000	90,000	0.70	500,000	650,000	195,000	560,000	420,000
8	80,000	50,000	0.60	48,000	40,000	56,000	72,000	56,000
6	80,000	50,000	0.40	200,000	225,000	140,000	250,000	170,000
7	185,000	150,000	0.40	330,000	230,000	230,000	440,000	230,000
1	70,000	50,000	0.25	225,000	260,000	180,000	190,000	211,000
5	55,000	30,000	0.55	65,000	43,000	58,000	58,000	60,000
2	40,000	30,000	0.60	60,000	30,000	43,000	46,000	38,000
9	200,000	150,000	0.60	215,000	145,000	285,000	215,000	250,000

Table continued on following page

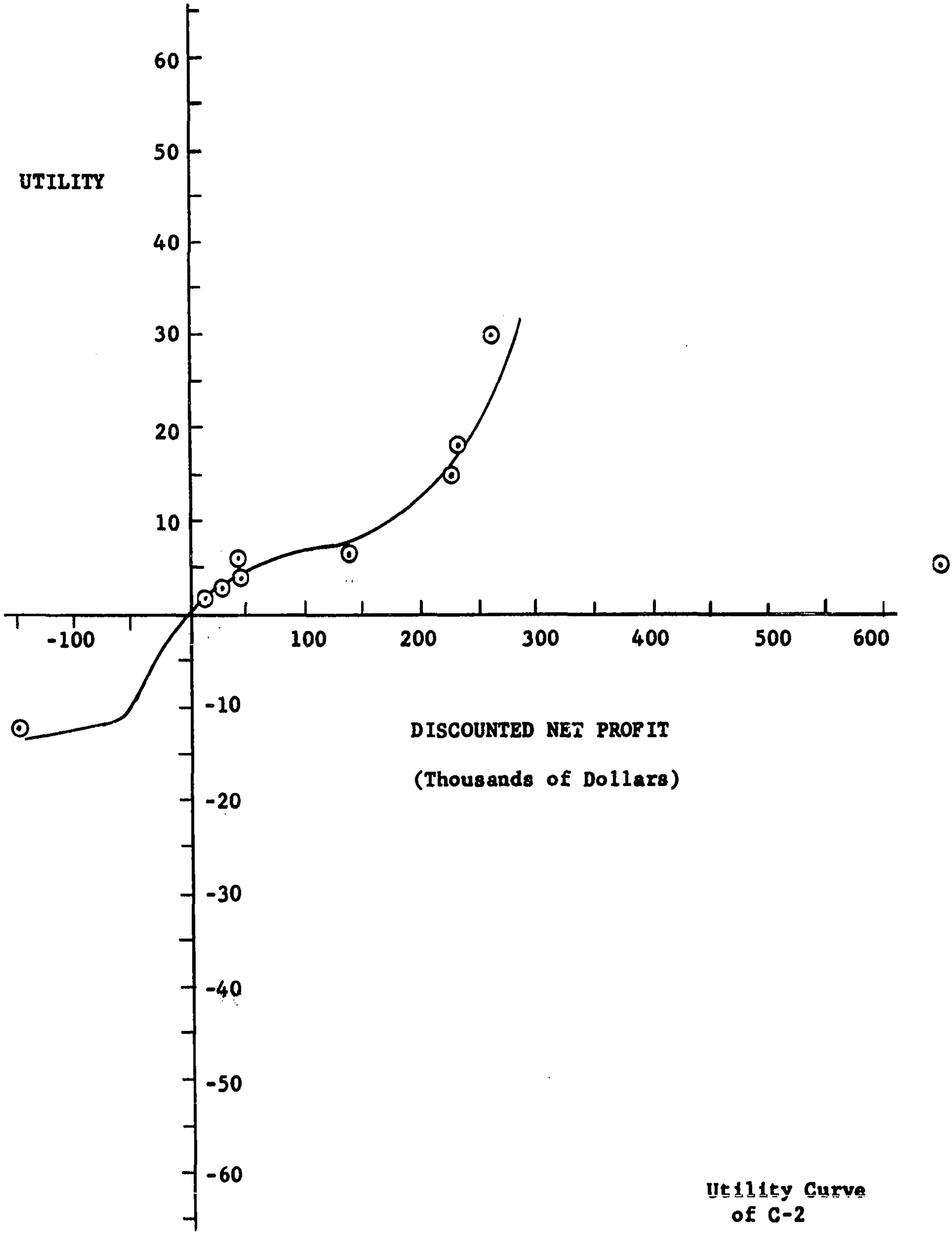
TABLE C - Continued

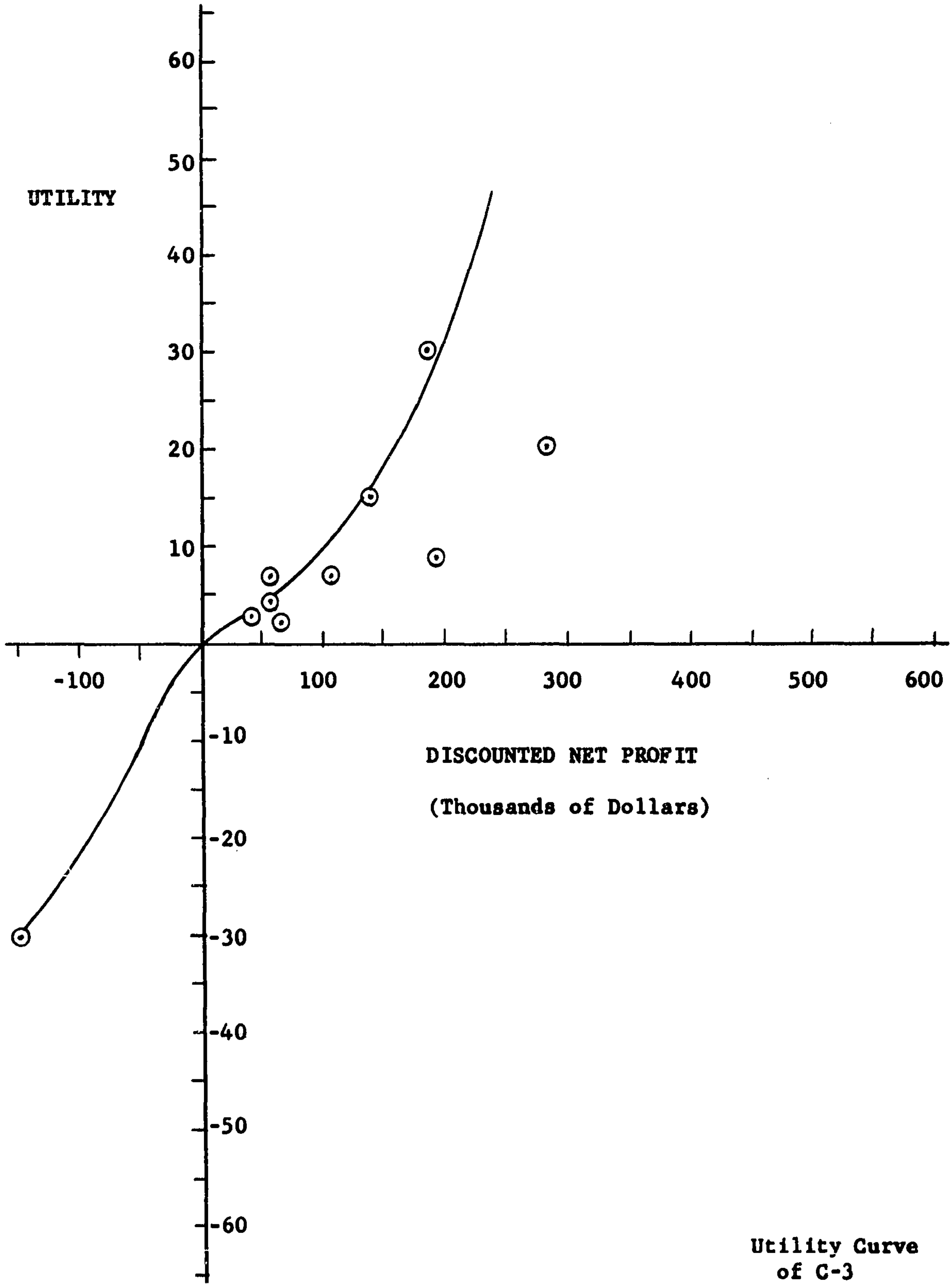
Proposal No.	Investment		Risk Factor	Indifference Points, Disc. Net Profits				
	Producer	Dry Hole		C-6	C-7	C-8	C-9	Composite
3	$ 50,000	$ 30,000	0.70	$ 30,000	$ 50,000	$ 20,000	$ 30,000	$ 35,000
4	70,000	50,000	0.60	170,000	105,000	170,000	45,000	122,000
10	150,000	90,000	0.70	600,000	235,000	320,000	235,000	413,000
8	80,000	50,000	0.60	54,000	86,000	56,000	48,000	57,000
6	80,000	50,000	0.40	200,000	375,000	250,000	140,000	217,000
7	185,000	150,000	0.40	(1)	370,000	500,000	155,000	311,000
1	70,000	50,000	0.25	175,000	(2)	350,000	325,000	239,000
5	55,000	30,000	0.55	43,000	98,000	43,000	35,000	56,000
2	40,000	30,000	0.60	100,000	(2)	30,000	114,000	58,000
9	200,000	150,000	0.60	485,000	(2)	485,000	215,000	287,000

(1) No response was given
(2) Respondent stated he was not interested in these proposals

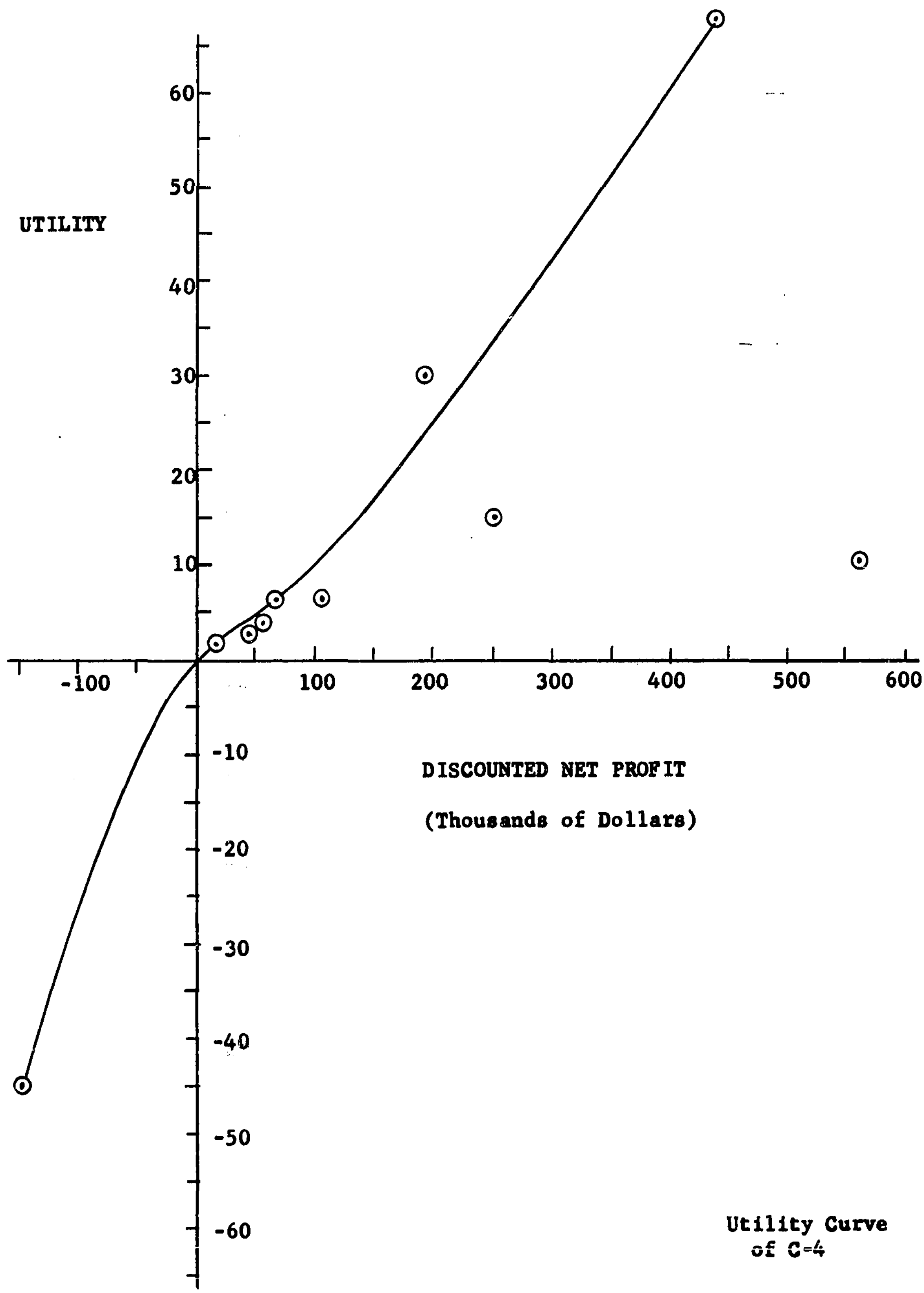


Utility Curve
of C-1

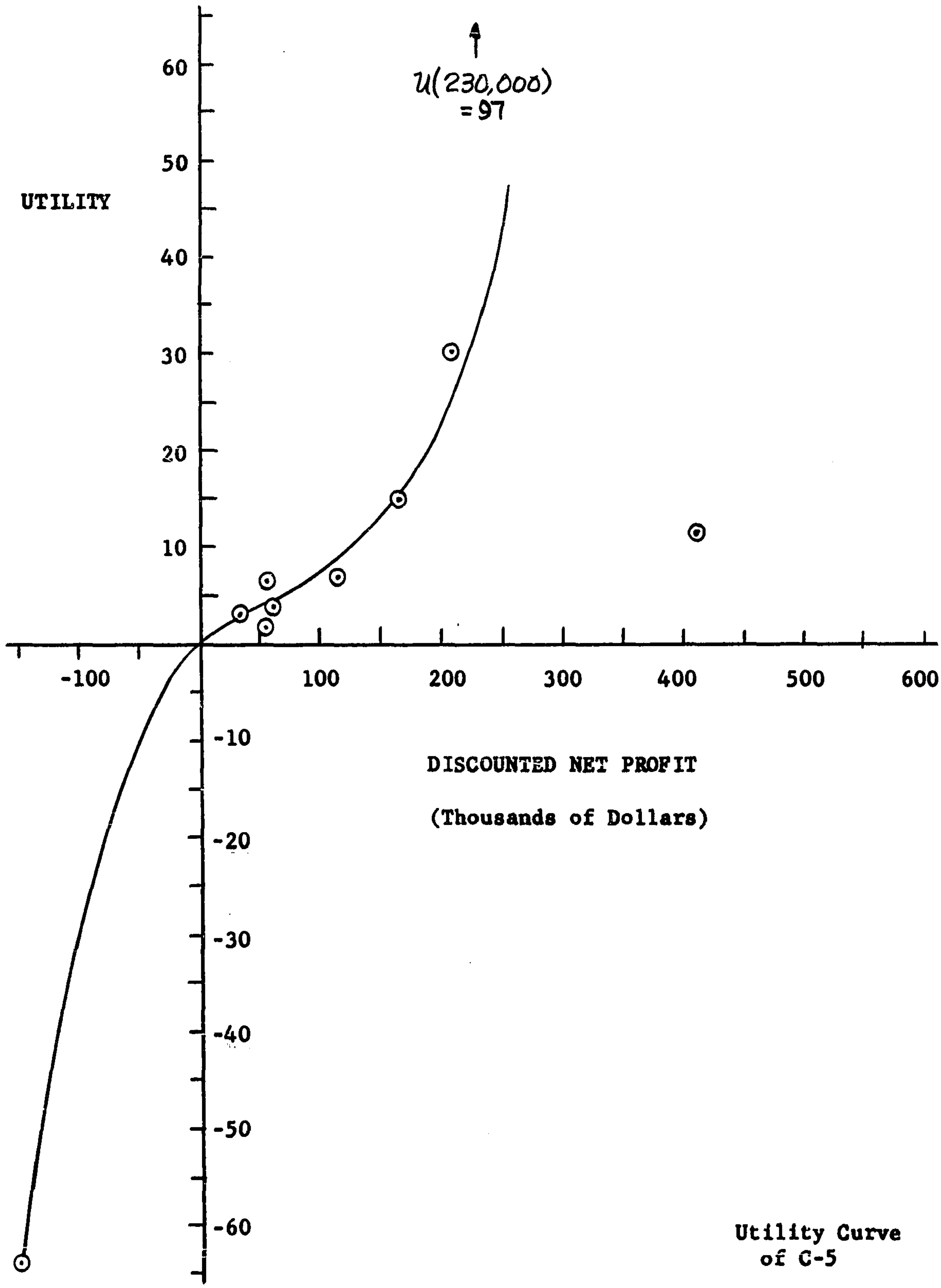

UTILITY
60
50
40
30
20
10
-10
-20
-30
-40
-50
-60
-100
100
200
300
400
500
600
DISCOUNTED NET PROFIT
(Thousands of Dollars)
Utility Curve
of C-2



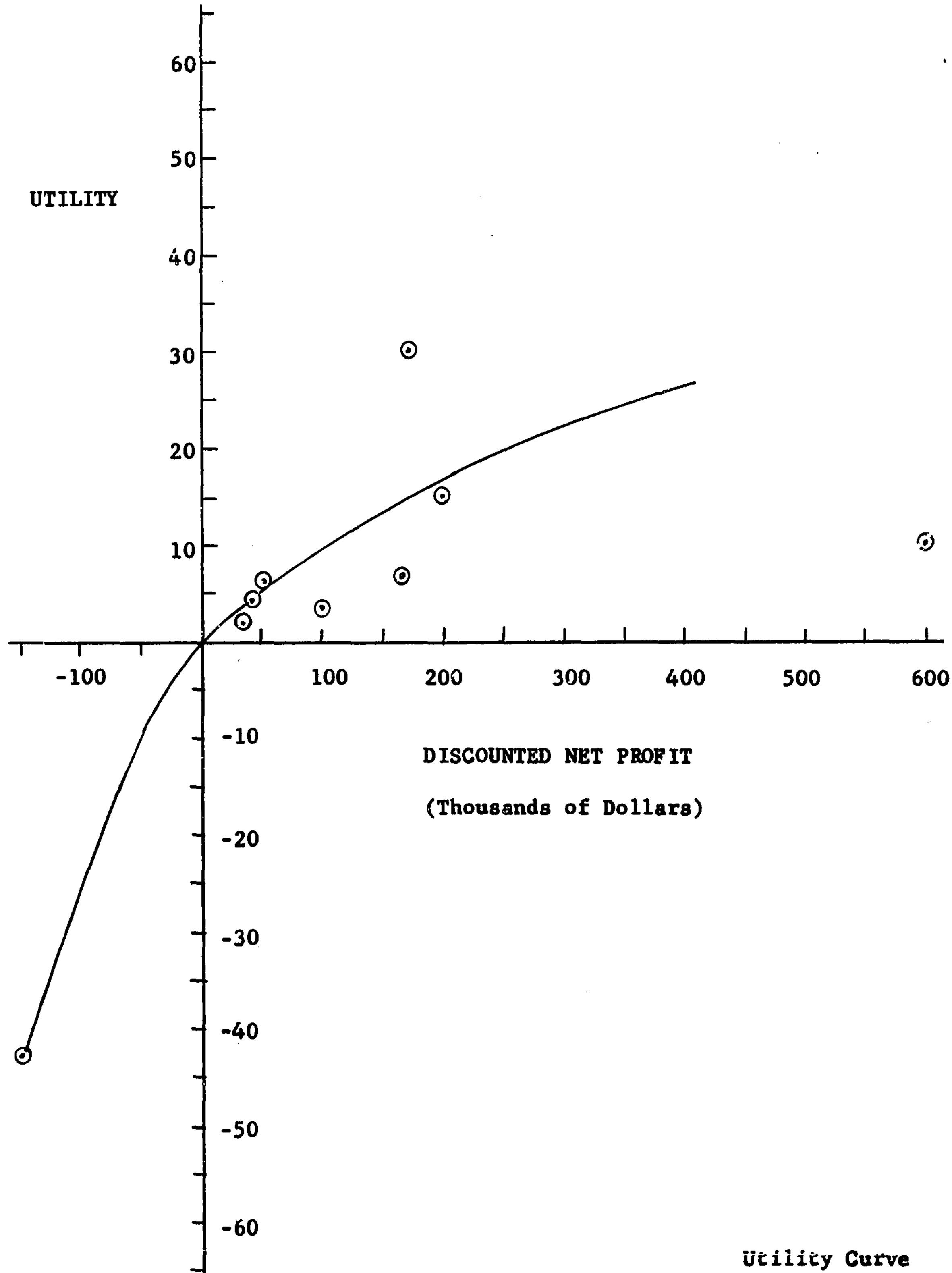
Utility Curve
of C-3



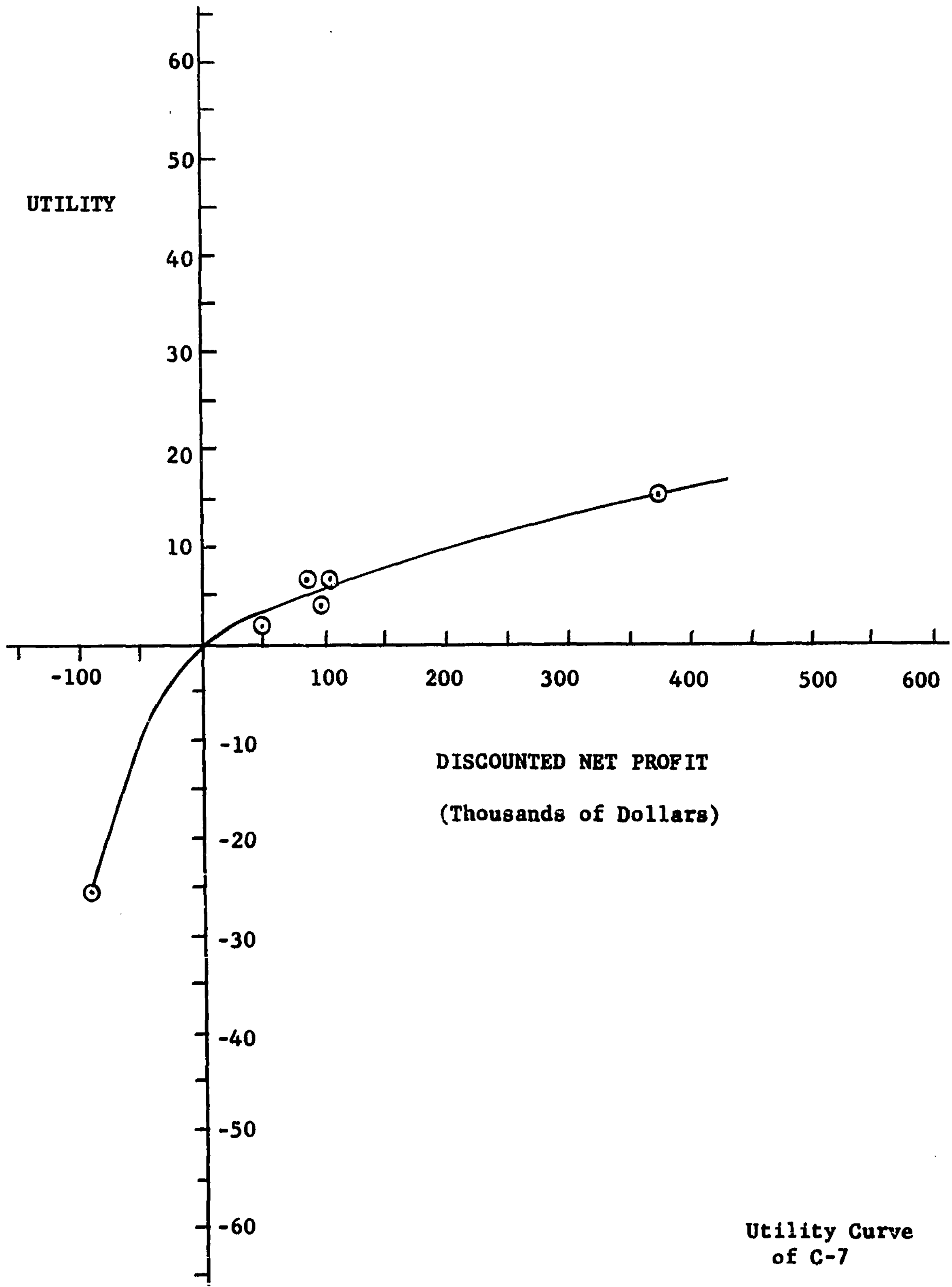
Utility Curve
of C-4



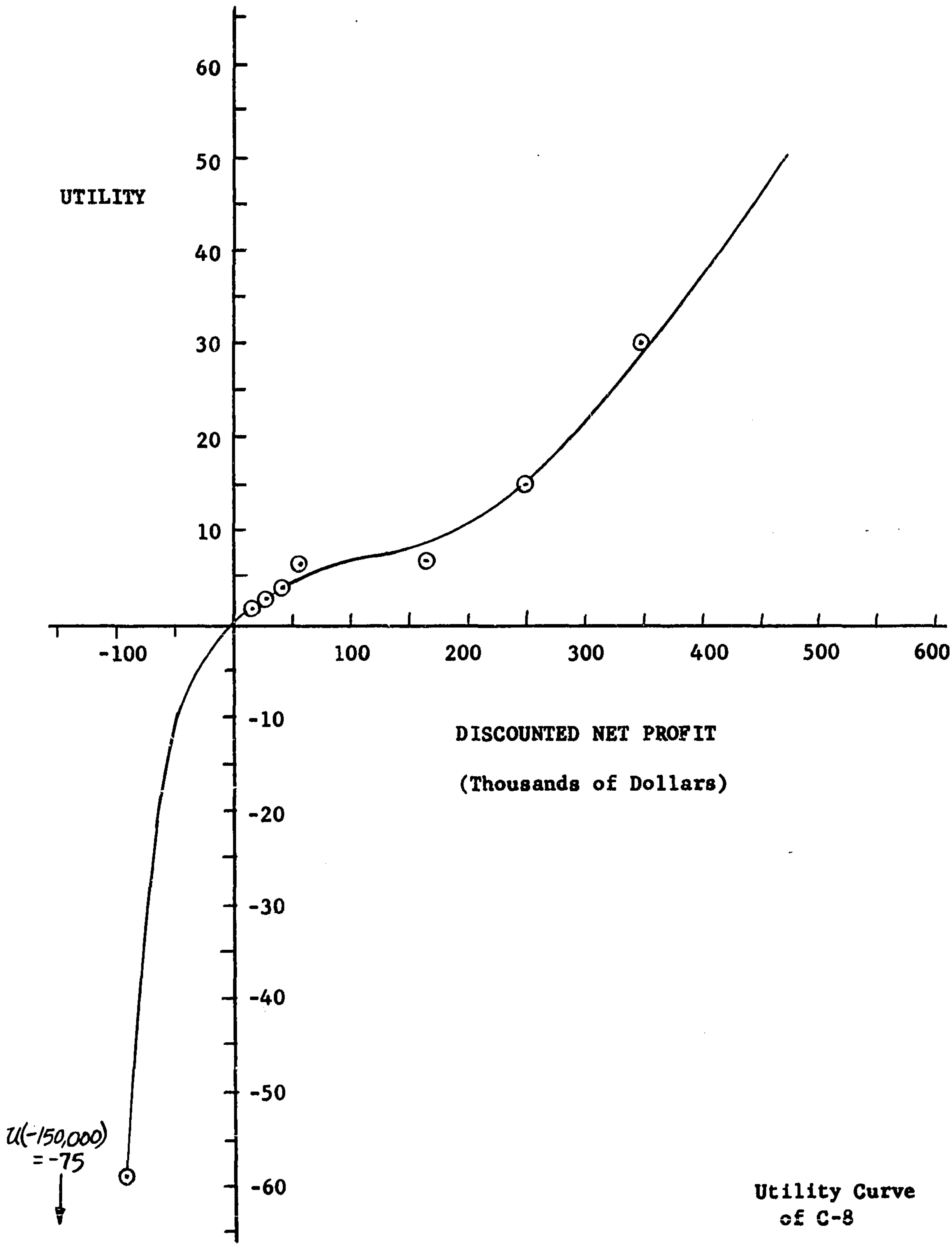
Utility Curve
of C-5



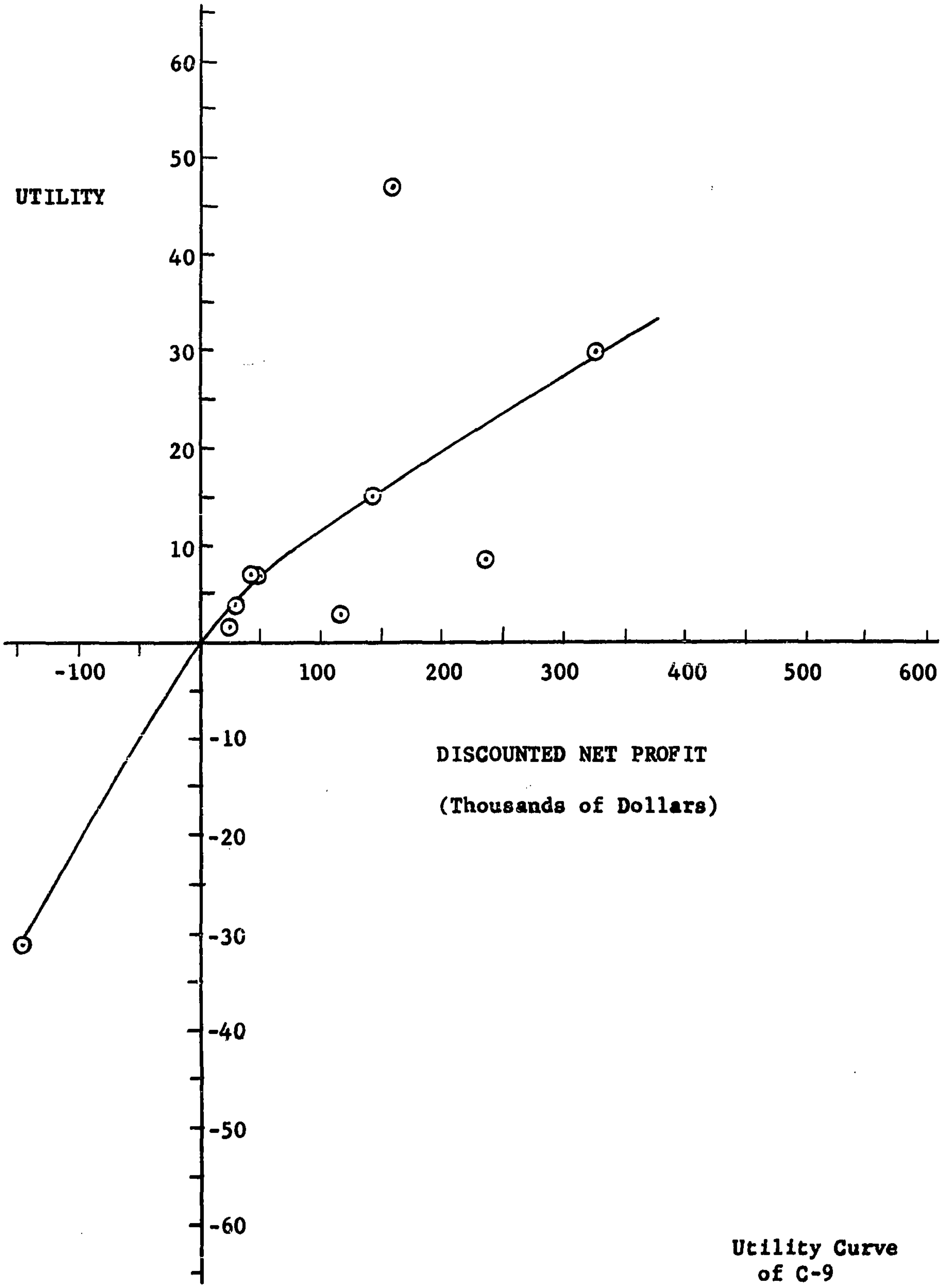
Utility Curve
of C-6



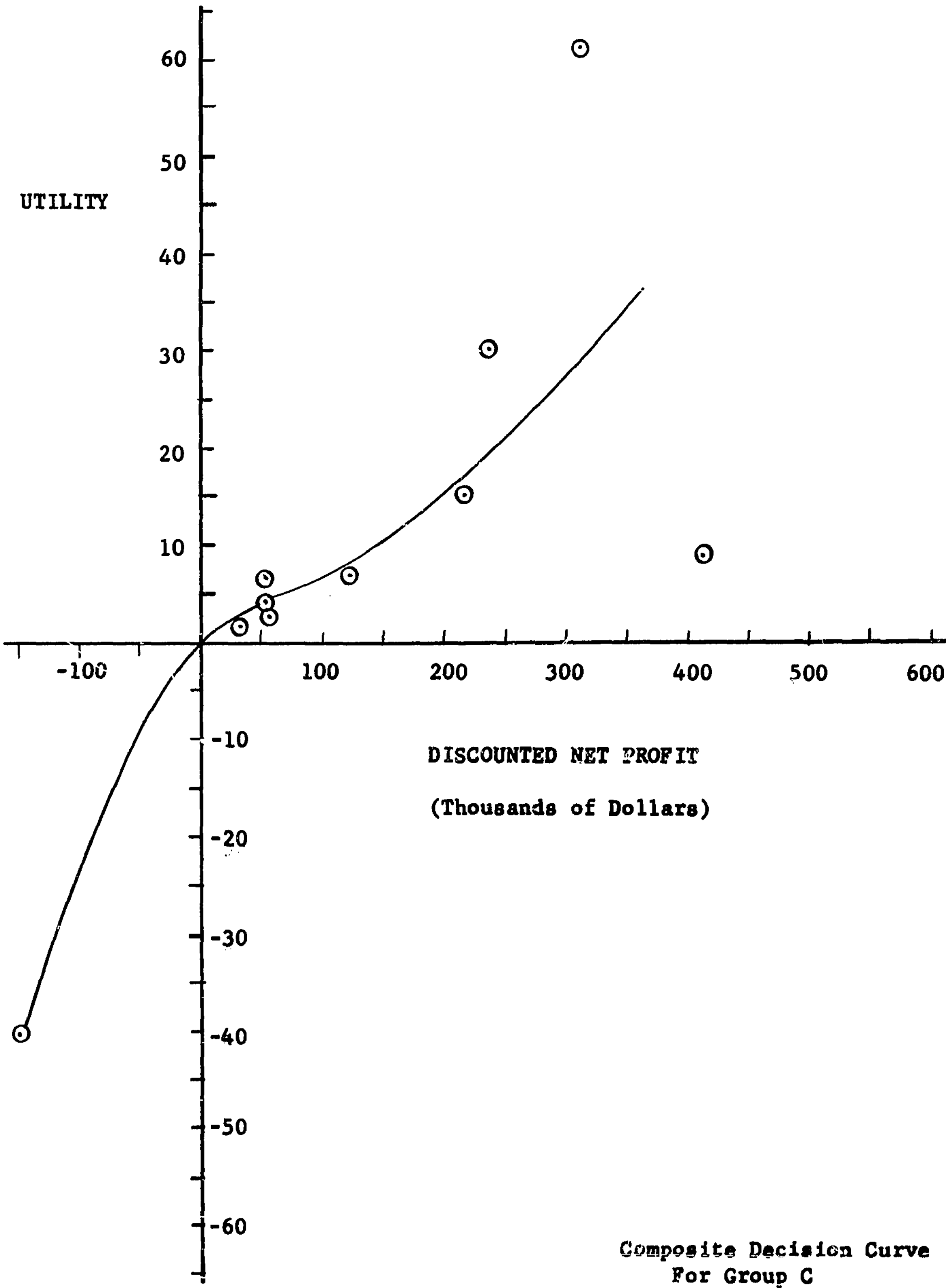
Utility Curve
of C-7



Utility Curve
of C-8



Utility Curve
of C-9



Composite Decision Curve
For Group C

COMMENTS - GROUP C

1) From the comments and questions asked during and after the testing, it was apparent that some of the members of the group had been exposed to utility theory before. All the participants appeared to give each proposal considerable thought before indicating their decisions. This extended the length of the testing to approximately two and one-half hours.

2) The utility curve shown for participant C-2 is not considered representative. His response for the four proposals with $50,000 dry hole costs and the three with $30,000 dry hole costs were generally consistent. The problem in constructing the curve occurred when extending it to higher profits and losses with the remaining responses. In comparing Proposals 6 and 7 both have the same risk but the latter is three times as costly. His stated indifference point was only $5,000 higher for the latter point, however. Roughly the same comparison is valid for Proposals 4 and 9. His responses, and hence the curve suggest that the loss of $150,000 is not much more undesirable than a loss of only $50,000. A more probable explanation is that additional testing points are needed to realistically construct his curve in the higher profit and loss range.

3) Proposals 4 and 8 have the same risk factor and the same dry hole costs. Yet all but one of the nine participants stated a higher indifference point for Proposal 4. Several were as much as three times higher. Proposal 4 is in a gas field and No. 8 is an oil prospect. It might be noted that, as a group, the responses to Nos. 3, 8, 5, and 2 were all quite low. All of these four prospects

are oil wells. This might suggest a management preference for oil well investments. During the testing it was mentioned that their company ceased most of their drilling in the Anadarko Basin (an active gas play during the last 5 years) about three years ago. This feeling might have influenced their responses in this test with respect to gas well proposals.

4) Respondent C-7 stated that he was not interested in three of the prospects. Since it was stated at the outset that they could set their indifference points as high as they cared to, the presumption is that the respondent was not interested under any circumstances. Only one of the three was an expensive well.

5) The utility curves of C-6 and C-9 are nearly identical as to general shape. Both are geologists, and both apparently view the drilling investments in much the same way.

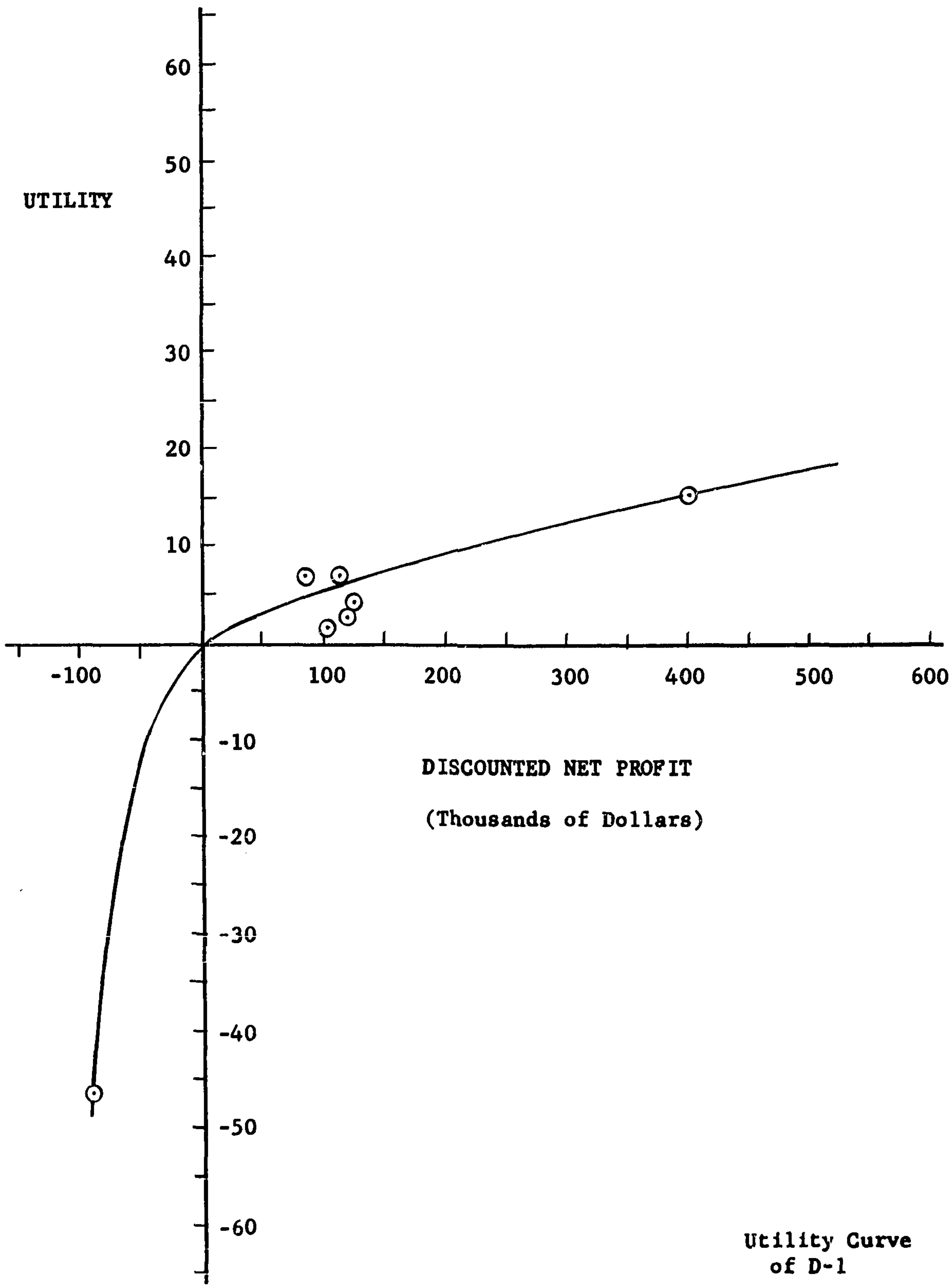
GROUP D

This group of participants was to have included the President and Vice-President of Production of a medium sized independent oil company. Emergency business commitments prevented the former from participating. Therefore, this group only consists of one participant, whose responses are given in Table D below. The company operates production in both Kansas and Oklahoma. The participant was conversant in utility theory; however, their company was not using expected utility as a decision criterion. The company normally does not participate in exploratory drilling programs or in wells costing over $200,000. For these reasons Proposals No. 1 and 9 were omitted.

TABLE D

DECISION RESPONSES OF GROUP D

Proposal Number	Investment Producer	Investment Dry Hole	Risk Factor	Indifference Point for D-1, Disc. Net Profit
3	$ 50,000	$ 30,000	0.70	$103,000
4	70,000	50,000	0.60	85,000
10	150,000	90,000	0.70	550,000
8	80,000	50,000	0.60	118,000
6	80,000	50,000	0.40	400,000
7	185,000	150,000	0.40	950,000
5	55,000	30,000	0.55	125,000
2	40,000	30,000	0.60	120,000



Utility Curve
of D-1

COMMENTS - GROUP D

1) Unfortunately many of the responses given by Participant D-1 were bunched around a net profit of $100,000. This prevented the clear definition of the shape of his utility curve in the profit range between $125,000 and $400,000. In general his utility curve suggests a rather conservative preference with respect to drilling investments. He stated that several proposals were such that the risk did not really justify drilling at all. For these proposals he stated high indifference points which resulted in the generally flat shape of the curve in the first quadrant.

2) His response given for Proposal 7 was not used because of insufficent data points for the extrapolation of the curve to either a loss of $150,000 or a profit of $950,000.