A PROCESS FOR TECHNOLOGY ASSESSMENT BASED ON DECISION ANALYSIS

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INTRODUCTION

The Office of Technology Assessment (OTA) is exploring the potential of alternative methodologies for technology assessment (TA). Decision analysis, a formal approach for identifying and analyzing rational decision-making behavior, is increasingly being used in the public and private sectors as a powerful aid for planning technology related decisions. This paper describes a TA process based on techniques and concepts of decision analysis and indicates how the approach might contribute to the objectives of OTA. Appendix A to the paper illustrates the TA process with an example dealing with synthetic crude oil. Appendix B reviews several recent OTA studies to investigate the extent to which elements of the proposed process are currently being used by the OTA.

A DECISION ANALYTIC INTERPRETATION OF OTA OBJECTIVES

One interpretation is that OTA's role is to provide a source of information responsive to decisions before Congress having a high technological content. OTA's 1979 Report to Congress states, "OTA's primary function is to provide congressional committees with assessments or studies that identify the range of probable consequences, social as well as physical, of policy alternatives affecting the uses of technology" (USOTA 1979)

Assuming OTA's role in TA is to support congressional decision making,

DECISION ANALYSIS

Decision analysis is a professional practice concerned with helping people make better decisions (Keeney and Raiffa 1976; Raiffa 1965). The intellectual roots of decision analysis are in several disciplines: psychology, where the interest is in how people decide and can be helped to decide more effectively; engineering, where the concern is to construct systems that interact efficiently with decision makers; and management science, whose goal is the efficient execution of the decision process. Important elements of decision analysis methodology include systems analysis for modeling complex relationships, probability theory for quantifying uncertainty, multiattribute utility theory for exploring value trade-off judgments, discounting to capture time preference, and Von Neumann-Morgernstern utility theory for representing risk attitude.

The application of decision analysis consists of decomposing the decision problem into its basic elements (choices, information, and preferences), quantifying each of these elements, and then applying axioms of normative decision theory to identify a logically consistent alternative. Several variations for accomplishing this are in use.

In the most basic approach, the decision analyst begins by asking the decision maker to create alternatives (choices) and to provide a set of variables, the outcome vector, on which the outcome will be judged. The decision maker is then asked to assign a joint probability distribution on the outcome vector for each alternative (information), and then to specify a multiattribute utility function (preferences) on the outcome vector. The best alternative, according to the axioms, is the one with the highest expected utility.

Although the basic procedure is conceptually simple, it places an onerous assessment burden on the decision maker. An important extension of the basic approach incorporates the creation of an extrapersonal model to distribute and ease the assessment problem (Howard 1975). Relying upon the information possessed by the decision maker or his delegates, the decision analyst constructs a model of the decision under consideration. The model specifies the relationships between the various systems variables: decisions, uncertainties, and outcomes. The model may be simple or extensive, depending on the nature of the decision problem and the resources available for the analysis.

An advantage of the modeling approach is that extrapersonalization of the decision model allows information to be collected from experts according to their specific areas of expertise; for example, lawyers on legal aspects and metallurgists on material technology. This is especially useful for public policy analysis, because the decision model serves as a vehicle for focusing all the information of the experts that the public policy decision maker may bring to bear on the problem while leaving him free to accept, reject, or modify this information and to establish preferences. It is the modeling approach to decision analysis that we take as the basis for decision-focused TA.

DESCRIPTION OF THE DECISION-FOCUSED TA PROCESS

OVERVIEW

There are four basic ingredients that must be brought together to produce effective decision-focused TA: content, process, methods, and management. Content consists of the basic inputs to decision making--information concerning the technology and its environment, social values for evaluating the consequences of the technology, and policy alternatives for implementing technological developments and for dealing with desirable and undesirable consequences of the technology. Process is the recipe for combining these elements to produce an evaluation and comparison of policy alternatives. Methods, such as forecasting techniques, mathematical modeling, discounting, and others are tools to facilitate the process. Finally, management, with its skills and commitment, serves to bring it all together.

This view points out the role of process in technology assessment. Content is primary, of course, because the results of analysis can never be better than its content. Process, however, not only ensures the full use of content, but can also lead to its improvement by identifying critical content areas.

A CONCEPTUAL FRAMEWORK FOR DECISION-FOCUSED TA

The proposed decision-focused TA process is structured into six major phases, as shown in Figure 1. The phases are problem definition, alternative generation, deterministic analysis, probabilistic analysis, informational analysis, and policy evaluation.

The major difference between the proposed approach and the typical TA process is the inclusion of alternative generation and analysis phases between the problem definition and policy evaluation phases. The analysis phases are applied iteratively: the sequence consisting of deterministic, probabilistic, and informational phases may be repeated several times before the assessment is complete. Current practice, by contrast, often leaps directly from the set of issues generated in problem definition to a choice of goals and policy recommendations. The intermediate phases of the decision-focused TA process are aimed at providing decision makers with a true choice of policy direction by creating and evaluating significantly different possible directions, rather than alternative ways to achieve the same goals.

The individual phases of the proposed process are described in the subsections below.

PROBLEM DEFINITION PHASE

The Problem Definition Phase is designed to produce three outputs: (1) problem bounding; (2) descriptions of the technology, its producers, its users, and the macroenvironment; and (3) key issues classified by priority levels.

Problem Bounding. At least six areas deserve consideration in problem bounding: the technology and its application areas, potential impact categories, geographic areas affected, appropriate time horizon, and stakeholders. Focusing on the decision to be made provides a guide to selecting the bounds for the assessment. Not everything relevant to the subject should be investigated, only those things that potentially influence the decision process.

<u>Technological and Social Descriptions</u>. In the development of technology and social descriptions, it is useful to start with a past/present view of the technology and its industry (or industries) and work outward to a past/present view of the macroenvironment and stakeholders. Past and present provide the reference points for answering the question, "How much could things change?" The discussion of the future should start with the macroenvironment: it is almost impossible to think of the future of the technology without such an overall context. Several possible future macroscenarios (for example, likely, optimistic, and pessimistic) should be considered. Here, some of the tools of futures research can be useful (Schwartz and Mitchell 1976). Once possible macroenvironmental futures are envisioned, it is relatively straightforward to consider first the microenvironment and then the technology itself. Again, technology descriptions should consider alternative implementations. This inside-out/outside-in approach is useful in that it helps reduce present bias.

<u>Issue Identification</u>. "Issues" are the major concerns resulting from the interaction between a developing technology and its social context. A key question for issues identification is, "Is current regulation adequate?" One strategy for identifying issues is along disciplinary lines, such as environmental, psychological, institutional/political, social, technological, legal, and economic (Porter et. al. 1980).

ALTERNATIVE GENERATION PHASE

The Alternative Generation Phase: (1) identifies specific decisions to be made and alternatives for each; (2) specifies representative strategy alternatives that are, in fact, significantly different policy directions; and (3) establishes relevant outcome variables to be used in evaluating alternatives.

<u>Decision and Alternative Identification</u>. As a first step to identifying alternatives, the decision responsibility and decision-making apparatus relevant to the problem should be identified. For a rapidly evolving technology, the responsibilities of government are likely to be unclear, overlapping, and only partially defined. To the extent possible, however, decisions facing the various governmental and quasi-governmental bodies that relate to the technology should be identified and organized into a hierarchy. High level decisions with major policy implications and broad consequences would be at the top of the hierarchy. Lower level decisions having more narrowly defined impacts would be placed lower in the hierarchy. For example, in a technology assessment of new cryptographic systems, national security is an issue because U.S. intelligence acquisition may be weakened if the Nation's enemies obtain easy access to highly secure secret codes. High level decisions might include whether Congress should attempt to establish laws increasing government powers to regulate private sector activities that threaten national security. A lower level decision would be whether the State Department should invoke a patent secrecy order to prevent dissemination or use of patent information dealing with a specific cryptographic technology.

An aid to alternative generation is to link significant issues with the formulation of effective policy to deal with them. It is tempting to deal with issues one by one, fixing on the first solution that comes to mind. This, however, overlooks the fact that issues and alternatives are fundamentally different. Issues reflect perceived problems; they may refer to either controllables or uncontrollables or a combination of the two. Alternatives, on the other hand, deal exclusively with the controllables, those decisions that constitute policy direction. Several decisions may deal with one issue simultaneously; similarly, one decision may deal with several issues.

Specification of Strategic Alternatives. The concept of a strategy alternative is central to the decision focused TA process. A strategy alternative is a combination of specific actions designed to implement a comprehensive policy for dealing with the technology and its impacts. Generating strategic alternatives begins by defining a few representative alternatives for each of the important decisions at the appropriate level in the decision hierarchy. Strategy alternatives are then created by forming meaningful combinations of the most important decisions. The specification of each strategy alternative ends with selection of a reasonable alternative for each of the remaining, lower-level decisions in the hierarchy.

Establishing Outcome Variables. Establishing outcome variables requires specifying the various first and higher order outcomes of interest that the set of alternatives might produce. These outcomes are the subsequent events that will determine the ultimate desirability of the situation. There is always a certain amount of arbitrariness in what to call an outcome. For decision analysis, however, an outcome is whatever the decision maker would like to know in retrospect to determine how the problem came out.

DETERMINISTIC ANALYSIS PHASE

The Deterministic Analysis Phase is essentially a systems analysis of the problem. There are two main steps in the deterministic phase: modeling the relationships among the variables affecting the decision and sensitivity analysis to measure the importance of the variables.

Modeling. Modeling in the deterministic phase consists of translating the verbal statement of the decision problem into a formal decision model suitable for computational analysis. There are two basic parts to the decision model: a systems model relating decision, uncertain, and outcome variables, and a preference model for representing social trade-off preferences.

The first step in developing a systems model is to structure the problem into its major components. Often, the physical processes establish the component structure. For example, in a TA of air pollution technology, major components would include models of the production/consumption processes that produce emissions, the atmospheric conversion and dispersion models for representing the distribution and transformation of pollutants, exposure models that specify conditions of exposure for the population at risk, and dose-response models that translate ambient concentrations into health and other adverse consequences. As the structural components are identified, systems variables that connect the various components with the outcome variables may be specified. Relationships among the systems variables are represented by specifying a set of equations, typically implemented by a computer program, connecting the systems variables. The process is one of successive refinement: outcome variables that would be difficult to estimate are related to other variables that are easier to assess. Ultimately, systems variables must be related to the decisions and alternatives that are assumed to be under the control of the decision maker. In practice, selecting systems variables and establishing relationships requires extensive consultation between the decision-makers, technical experts, and the analysts.

The preference model provides a means for explicitly representing value judgments and enabling decision makers to investigate the sensitivity of decisions to alternative value assumptions. Although in some cases the decision can be reached as a result of ordering outcomes in terms of desirability, more insight is available if a numerical (cardinal) model of social preference is used.

In decision analysis, the model of preferences is typically divided into three parts: value assessment, time preference, and risk preference. Only value assessment and time preference are considered in the deterministic phase.

Value assessment refers to trading off one type of outcome for another, such as deaths for injuries, or restriction in land use for money. These trade-offs are especially difficult for social decision making: because monetary resources are to be allocated, logic demands that trade-offs be approached directly in monetary terms. Thus, the value of human life, morbidity, and other social outcomes of interest must be measured in terms of dollars and cents. Obtaining precise trade-off values is not necessary, however. The intent in assigning trade-off values is not to define a precise dollar equivalent for non-economic consequences, but to encode value assignments consistently.

Time preference requires trading values in the future for values today. In the extreme, this becomes a question of asking what one generation owes the next. Time preference is usually modeled by discounting values occurring in future periods using an appropriate discount rate.

The various elements of the decision model are summarized in Figure 2. When the decision variables in the model are set according to a given strategic alternative, the systems model produces an estimate of the outcomes to be produced, and the preference model converts these outcomes to a single value measure. The value measure output by the model may be interpreted as an estimate of the net social benefit resulting from the selection of a specific policy direction.

<u>Sensitivity Analysis</u>. Sensitivity analysis in the deterministic phase consists of observing how changes in the variables in the decision model affect net social benefit. In the simplest sensitivity analysis, each uncertain input variable is varied across a range of values selected to approximate its range of uncertainty while holding all other variables constant at their nominal ("best guess") values. Those variables whose variations produce the greatest change in estimated net social benefit are most critical to the assessment and are referred to as "crucial" uncertainties.

Because functional relationships used in the model will be uncertain, crucial uncertainties may include parameters that specify alternative

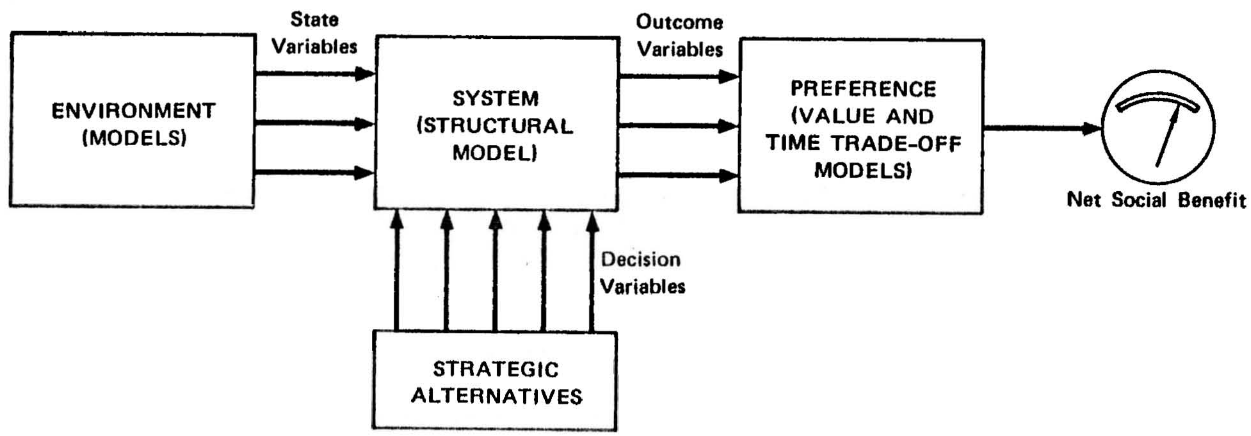


FIGURE 2 ELEMENTS OF THE DECISION MODEL

functional relationships or submodels. If a particular functional relationship assumed or submodel used is shown to be highly sensitive, it should be refined, if possible, and any simplifying approximations previously introduced should be removed.

Single variable sensitivities may not identify crucial uncertainties whose importance results from probabilistic dependencies. Therefore, joint sensitivities should be measured in which two or more of the input variables are simultaneously varied across their respective ranges of uncertainty. The large number of variables in the model makes it impractical to measure all possible combinations of joint sensitivities. Fortunately, knowledge of model structure and experience in conducting sensitivity analyses enable a limited number of necessary joint sensitivities to be identified to avoid missing crucial variables.

PROBABILISTIC ANALYSIS PHASE

The Probabilistic Analysis Phase involves: (1) encoding uncertainty on crucial variables, (2) developing value lotteries on net social benefit, and (3) measuring risk sensitivity and encoding risk preference.

Encoding Uncertainty. The first step in the probabilistic phase is the assignment of probability distributions to the variables identified as crucial by sensitivity analysis. Crucial variables may be single uncontrollable factors or entire scenarios describing possible future environments. Probability distributions should be elicited from experts using probability encoding techniques.

Experts identified for probability encoding should have substantial expertise in the relevant area and should have the confidence of the decision makers, OTA, and the public. In situations where differences in scientific opinions exist, experts should be chosen to encompass each credible point of view.

Because most individuals have real difficulty in thinking about uncertainty, the method of extracting the probability distributions is extremely important. Individuals with some experience with probability often attempt to make their distributions look like normal distributions, a characteristic known as "bell-shaped" thinking. Although normal distributions are appropriate priors in some circumstances, they should not be foregone conclusions.

Experience has shown a number of encoding procedures to be effective. The three basic types of encoding methods are: probability methods, which require the subject to respond by specifying points on the probability scale while the values remain fixed; value methods, which require the subject to respond by specifying points on the value scale while the probabilities remain fixed; and probability/value methods, which ask questions that must be answered on both scales jointly (the subject essentially describes points on the cumulative distribution) (Stael von Holstein and Matheson 1979). Each of these encoding procedures may be presented either in a direct or indirect response mode. In the direct response mode, the subject is asked questions that require numbers as answers. In the indirect response mode, the subject is asked to choose between two or more bets. The bets are adjusted until the subject is indifferent in choosing between them. Either external reference events (alternative bets defined on some external event, such as a probability wheel) or internal reference events (events defined on the same value scale as the uncertain quantity) can be used in the indirect mode. Table 1 summarizes the set of available encoding methods.

If any set of crucial variables is dependent, in the sense that knowledge of one would provide information about the others, then the probability assignments on any one variable must be conditioned on the values of the others. Gathering these assignments amounts to asking such questions as, "What are the odds that sales of the technology will exceed 10 million units in the first year?"

Differences in the distributions assessed from various experts can often be resolved by bringing the experts together and allowing them to share information. Nevertheless, there will be many situations where it is impossible for experts to reach agreement on an appropriate probability distribution. In such situations, we suggest grouping divergent priors into nominal, optimistic, and pessimistic sets. Whether the expert differences are significant and must be retained can then be determined through sensitivity analysis.

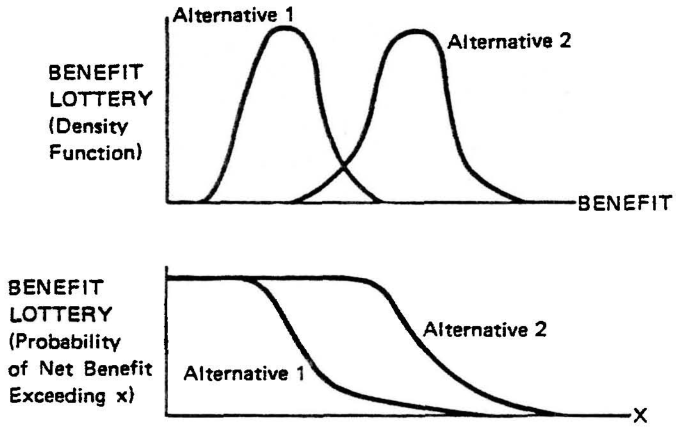
Value Lotteries. Having developed a decision model and obtained probability distributions on the crucial state variables, it is straightforward to design a computer program that will generate the probability distribution over the measure of net social benefit for various strategic alternatives. This probability distribution is a lottery in the sense that it summarizes uncertainty in the social benefit to be derived from a given policy direction.

One important principle that allows judging one lottery as being better than another is that of stochastic dominance, which is illustrated in Figure 3. Part A of this figure shows the lottery for two alternatives

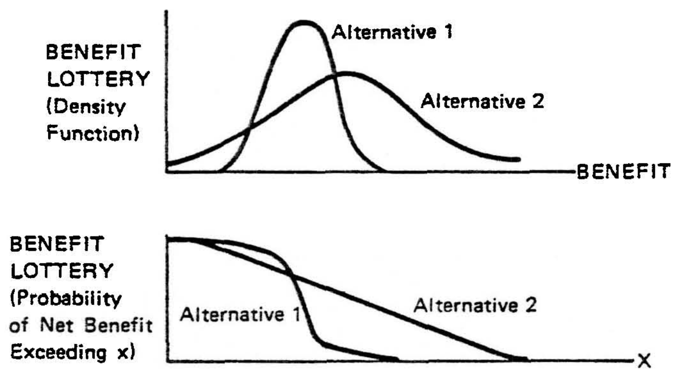
Table 1

CLASSIFICATION OF PROBABILITY ENCODING TECHNIQUES

Encoding Method	Response Mode: Indirect — External Reference Events	Response Mode: Indirect — Internal Events	Response Mode: Direct
Probability (value fixed)	Probability wheel	Relative likelihoods	Cumulative probability
Value (probability fixed)	Probability wheel Fixed probability events	Interval technique	Fractiles
Probability-Value (neither fixed)	--	--	Drawing graph; Verbal encoding



PART A – STOCHASTIC DOMINANCE



PART B – LACK OF STOCHASTIC DOMINANCE

FIGURE 3 USING THE LOTTERY ON NET SOCIAL BENEFIT TO IDENTIFY STOCHASTIC DOMINANCE in both probability densities and excess probability distribution forms. The excess probability distribution, or excess distribution, is the probability that the variable will exceed any given value plotted as a function of that value. Its height at any point is the area under the probability density function to the right of that point. Comparison of the excess distributions for the two alternatives reveals that, for any value of X, there is a higher probability that alternative 2 will produce a social benefit in excess of that X than will alternative 1. This is called a condition of stochastic dominance. A decision-maker preferring more net social value to less would prefer alternative 2. If stochastic dominance exists, there is no need to investigate the importance of risk aversion.

Part B of Figure 3 illustrates a case in which stochastic dominance does not exist. The excess distributions on net social benefit for the two alternatives cross. If the decision-maker wants to maximize the chance of achieving at least a small amount of social benefit, he would prefer alternative 1; if he wants to maximize his chance of achieving at least a large amount of social benefit, he would prefer alternative 2. In situations like this, where stochastic dominance does not apply, the importance of risk preference should be evaluated.

Risk Preference and Risk Sensitivity. According to the theory of decision analysis, if a decision maker agrees to a set of axioms about risk taking, his risk preference can be represented by a utility curve like that shown in Figure 4. This curve assigns a utility to any outcome value. As a consequence of the risk preference axioms, the decision-maker's rating of any lottery can be computed by multiplying the utility of any possible worth in the lottery by the probability of that value and then summing over

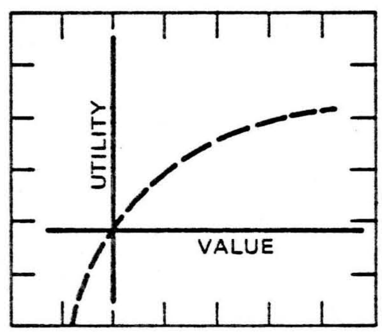


FIGURE 4   A TYPICAL UTILITY CURE

all possible values. This rating is called the expected utility of the lottery.

If one lottery has a higher expected utility than another, then it must be preferred by the decision-maker if he is to remain consistent with the axioms. Thus, the utility curve provides a practical method of incorporating risk preference into the decision model.

Although the expected utility rating provides a quantitative ranking of expected social benefit, its numerical value has no particular intuitive meaning. By using the utility curve in reverse, the value corresponding to the expected utility of a lottery can be obtained; this quantity is called the certain equivalent of the lottery. The certain equivalent of any lottery is the amount received for certain, so that the decision-maker would be indifferent between receiving this value and participating in the lottery.

A useful calculation in the probabilistic phase is to check risk sensitivity. In some cases, it is possible to approximate the utility curve by an exponential function that permits risk attitude to be characterized by a single number--the risk tolerance. When the exponential approximation is applicable, we can interpret it as a direct measure of the decision-makers willingness to accept a risk. In many situations when certain equivalents are computed for each available alternative, the ranking of certain equivalents will be the same or at least the same alternative will have the highest certain equivalent for all reasonable values of risk tolerance. In such cases, there is little reason to argue over the desirable extent of risk aversion and a source of controversy can be eliminated. (See Appendix A for an example.)

INFORMATIONAL ANALYSIS PHASE

In the Informational Analysis Phase the analyst (1) determines the value of eliminating uncertainty on crucial variables, (2) gathers additional information and expands the decision model, and (3) repeats the deterministic and probabilistic phases to refine the analysis.

Determining the Value of Eliminating Uncertainty. The fundamental idea in the informational phase is that of placing a monetary value on additional information. A conceptual aid to computing this value is the concept of a clairvoyant. Suppose someone exists who knows in advance just what value of a particular crucial variable would result in the decision problem. How much should the decision maker be willing to pay to obtain the clairvoyant's information?

The answer to this question may be obtained through the following reasoning. Suppose we engage the clairvoyant at a cost k, and then he tells us that the crucial variable will take on the value s. We can use the decision model to determine the expected utility of the entire decision problem including the payment to the clairvoyant, all conditional on his reporting s.

Before engaging the clairvoyant, however, the probability to be assigned to his reporting s as the value of the particular crucial variable is described by the probability distribution showing the current state of knowledge on this variable. Consequently, we obtain the expected utility of purchasing information on the variable at a cost k by multiplying the expected utility of the information given that he reports s and costs k, by the current probability that he will report s and then summing over all values of s.

Knowing the expected utility of purchasing the information from the clairvoyant at a cost of k, we can gradually increase k from zero until the expected utility with purchase of the information is just equal to the expected utility of proceeding with the decision without purchase of the information. The value of k that establishes this equivalence is the value of clairvoyance on the crucial variable.

The value of clairvoyance on a crucial variable is a useful result because it represents an upper bound on the payment for any experimental program designed to provide information on this variable, for no such program could be worth more than clairvoyance. The reasoning can be extended to show how to compute the value of less-than-perfect information. Whereas the clairvoyant would report a particular value s for a crucial variable, a typical experimental or data gathering program will provide only a new probability distribution for the variable. The analyst would then determine the best decision, given this new probability distribution, and compute the expected utility of the decision problem. He would next multiply the expected utility by the probability that the experimental program would come out this way and sum over all possible outcomes of the experimental program. The cost of the experimental program that would make this expected utility just equal to the expected utility without the experimental program would be the value of the imperfect information generated by the experimental program.

Gathering Additional Information. Once the value of information has been computed for crucial uncertainties, relevant information gathering alternatives must be identified, such as surveys, laboratory programs, or computer modeling, to find which, if any, are expected to make a cost-effective contribution to the assessment. In principle, an information gathering alternative will be cost effective if its cost is less than the value of the information produced.

The most effective information gathering programs available will generally be time consuming as well as costly. Selection of specific steps to be taken to improve information must, therefore, be based not only on results of calculations such as those described above, but also on the time required to obtain the information.

Refining the Decision Model and Updating the Analysis. When the preferred information gathering program is performed, it will lead to new probability assignments on the crucial variables and may also result in changing the basic structure of the decision model. When all changes that have been implied by results of the information gathering are incorporated, the deterministic and probabilistic phases are repeated. As the model is improved, the effectiveness of further changes in improving the decision model will begin to decline, as measured by the value of further information. By using sensitivity analysis and value of information calculations, the analyst can direct the assessment by developing only those elements of the decision model that are most effective in clarifying the decision under consideration.

ALTERNATIVE EVALUATION PHASE

Daniel V. Desimone, past Deputy Director of the OTA, has stated that the purpose of TA is to inform Congress, within as complete a context as feasible, of the predicted consequences of various policy options, but not to recommend any one option (RTA Conference 1977). This point of view is compatible with the decision focused TA process. The strategic alternatives evaluated by repeated applications of the deterministic, probabilistic, and informational phases will result in estimates of the social benefit associated with different alternatives, but these estimates represent the logical consequences of specific judgmental information and preferences represented in a quantitative model that at best is a simplified approximation of the actual decision situation. Policy recommendations may differ from the results of the analysis either because of considerations that could not adequately be modeled or because decision makers may wish to assume different probabilities for crucial uncertainties or different value judgments than those represented in the analysis.

Because the TA is an aid to the decision process rather than a replacement for it, the potential users who face decisions should have ample opportunity to guide the analysis through selecting the experts who provide structural information and probability assessments, and by establishing preferences. Because the decision model represents a device for conducting sensitivity analyses, decision-makers may find it useful to request additional sensitivity studies. These additional sensitivity studies represent an important element of the Alternative Evaluation Phase.

The results of the assessment should be assembled in a form suitable for intensive review by the decision makers. The presentation should include all information and analyses relating to each strategy alternative as well as a clear statement of the trade-offs used and the simplifying assumptions made in the quantitative analysis. Close interaction between the users of the assessment and the analysts at all stages of the assessment process will ensure that information produced by the assessment process will be of value to decision-makers in their evaluation of alternatives.

SUMMARY

The key aspect of the decision-focused TA process described above is an iterative cycle consisting of deterministic, probabilistic, and informational analysis. Inserting these phases in the TA process results in the construction of a formal decision model that generates insights and serves to guide the assessment process. In some situations it will be extremely difficult to quantify adequately all important aspects of a problem. Nevertheless, constructing a simple, but comprehensive model of the decision provides a framework that forces a disciplined and systematic investigation of relevant issues. Furthermore, the decision model permits alternative strategic policies for dealing with the technology to be evaluated in a consistent manner. The result of the decision-focused TA process is thus information directly useful to congressional policy makers who must deal with the uncertain and long term impacts of emerging technologies.

Appendix A

AN ILLUSTRATION OF A DECISION-FOCUSED TA PROCESS

DECISION ANALYSIS OF A SYNTHETIC FUELS COMMERCIALIZATION PROGRAM

INTRODUCTION

To help clarify the decision-focused TA process, we present an analysis conducted in 1975 by the SRI Decision Analysis Group for the Interagency Task Force on Synthetic Fuel (Tani 1978). Although the analysis does not exactly follow each step in the proposed TA process, major elements of the conceptual framework are illustrated. The description is organized according to the basic phases of the TA process as outlined in the body of this report.

PROBLEM DEFINITION

Technology exists to produce synthetic crude oil from shale and a variety of clean, solid, liquid, and gaseous fuels derived from coal, but because of the many uncertainties involved and the large capital investments required, private industry has lagged in the commercialization of the technology. In 1975, President Gerald Ford proposed a federal incentive program with a goal of achieving commercial production of one million barrels per day of synthetic fuels by 1985. The decision motivating the analysis was, thus, whether to implement a program of financial and regulatory incentives to stimulate private sector investment in commercial-scale plants to convert coal, oil shale, and other relatively abundant domestic resources into clean liquid and gaseous fuels.

Benefits identified for a synthetic fuels program included:

1. An accelerated accumulation of experience and information on the technical, environmental, economic, and institutional aspects of commercial-scale synthetic fuel production for better-informed private sector investment decisions.
2. The development of an industry infrastructure to support subsequent expansion of the synthetic fuels industry.
3. Insurance against high world oil prices and against early depletion of domestic sources of conventional fuels.
4. Protection against the losses of an oil embargo.
5. Improvement in the U.S. international bargaining position.

These benefits, however, would be counterbalanced by the possible costs of subsidizing synthetic fuels relative to less expensive energy sources and by the environmental and socio-economic costs associated with rapid development of coal and oil shale reserves.

ALTERNATIVE GENERATION

The fundamental question addressed by the analysis was whether the United States should have a synthetic fuels commercialization program and, if so, how large the program should be. Four strategic alternatives were selected for evaluation:

1. No Program--No federal funding of synthetic fuels commercialization but continuation of research and development.
2. Informational Program--A minimal program designed primarily to generate technical, environmental, and economic data on various resource-to-fuel conversion

processes, with synthetic fuel production of about 350,000 barrels per day by 1985.

3. Medium Program--A program designed to generate more complete information on a wider range of processes and to meet the President's goal of 1,000,000 barrels per day by 1985.

4. Maximum Program--A program designed to achieve the greatest amount of synthetic fuel production in 1985 possible without causing major dislocations in the economy: 1,700,000 barrels per day.

The objective of the analysis was to determine which of these alternatives would be of greatest net benefit to the nation as a whole, where net benefit was defined to include three components: economic impact, embargo protection, and environmental and socio-economic impacts.

Outcome Measure for Economic Impact. Economic impact was decomposed into impact on consumers and impact on producers. To measure the economic impact on consumers, the concept of consumer surplus was used. Consumer surplus is the difference between the value of a good to consumers and the amount of money they must pay for it. This is shown graphically by the demand curve in Figure A1. If the market price is p, then q units will be purchased. For every unit except the last one, the value of the good exceeds the price paid for it. The shaded area between the price line and the demand curve represents the total excess value that consumers receive from this good; this is called the consumer surplus.

In the case of the synthetic fuels program, it was felt that a demonstration that synthetic fuels could be produced cheaply would have the

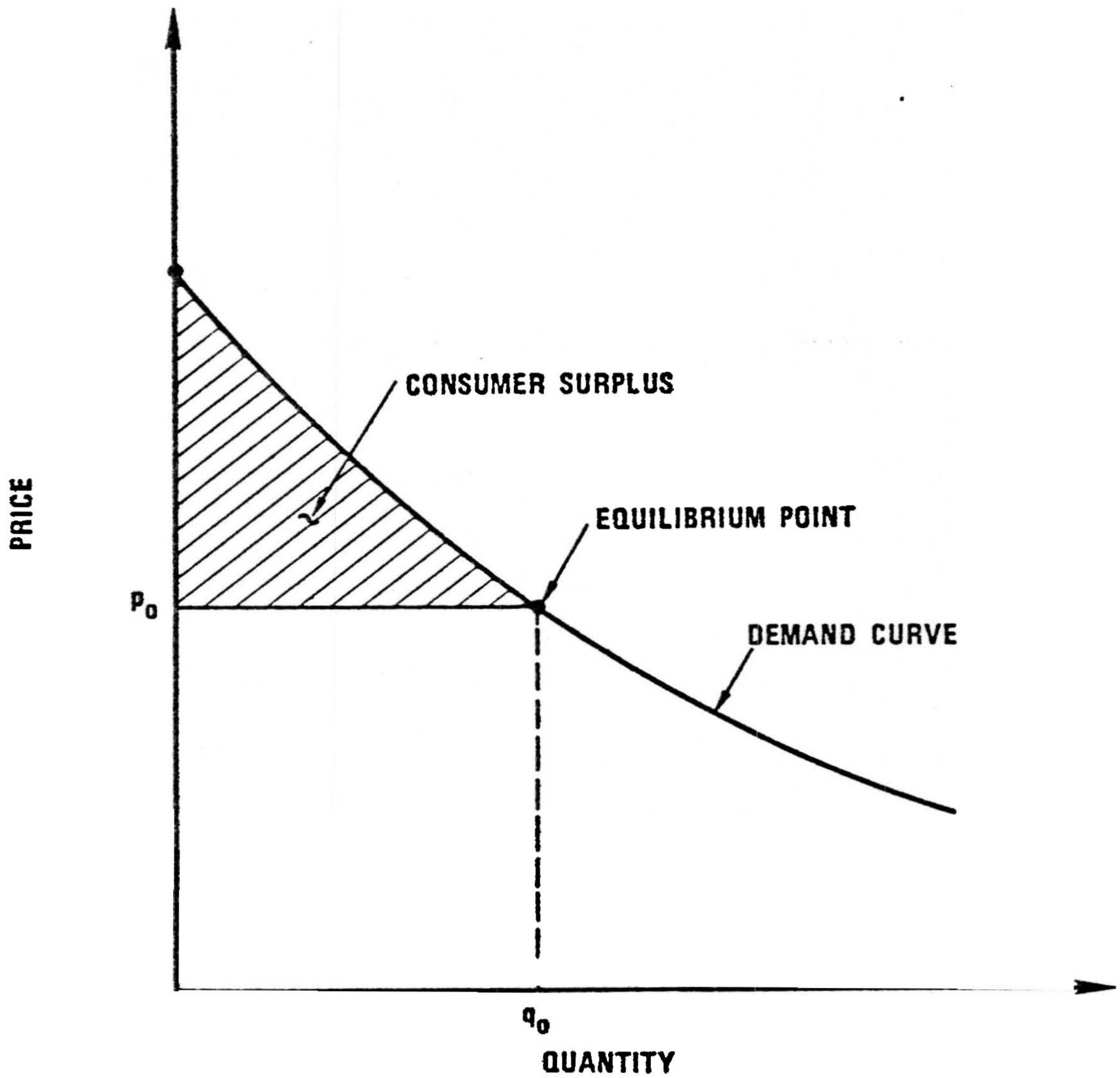


FIGURE A1 CONSUMER SURPLUS

effect of holding down the price of imported oil. The resulting increase in consumer surplus would then be credited as a positive benefit of the program.

To measure the impact on producers, a concept analogous to that of consumer surplus was used--producer surplus. This is the difference between the amount producers receive for a good and their marginal cost of producing it. Producer surplus is thus directly related to the idea of profitability. Figure A2 shows producer surplus graphically. The supply curve represents the marginal cost of producing each unit of the good, which is the least amount of money the producers would accept for it. The shaded area between the price line and the supply curve is equal to the total producer surplus for that good.

It was assumed in the analysis that synthetic fuel would be a substitute for imported oil. Therefore, if the cost of the synthetic fuels turned out to be less than the cost of imported oil, the industry would accrue positive producer surplus, which would be credited to the program as a benefit. However, if synthetic fuels turned out to be costlier than imported oil, producer surplus would be negative and industry would require a subsidy from the government to cover its losses. The amount of this negative producer surplus would be charged as a cost of the program.

The algebraic sum of consumer and producer surplus was taken as the measure of the total economic impact of the program on the nation assuming normal market conditions.

Outcome Measure for Embargo Protection. The situation during an oil embargo is illustrated in Figure A3. The pre-embargo price and quantity of oil are established on the long-term demand curve. If an embargo occurs,

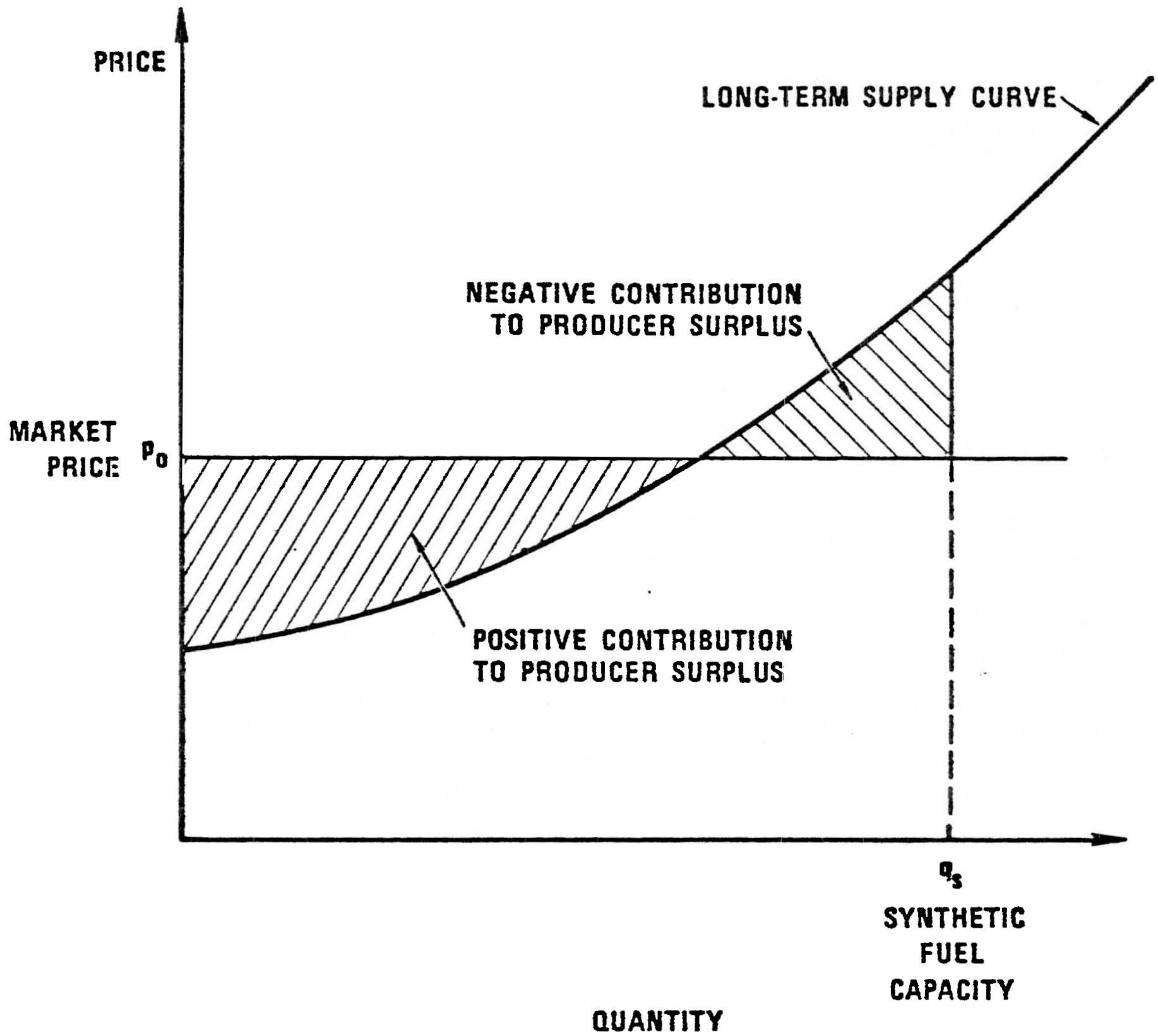


FIGURE A2 PRODUCER SURPLUS

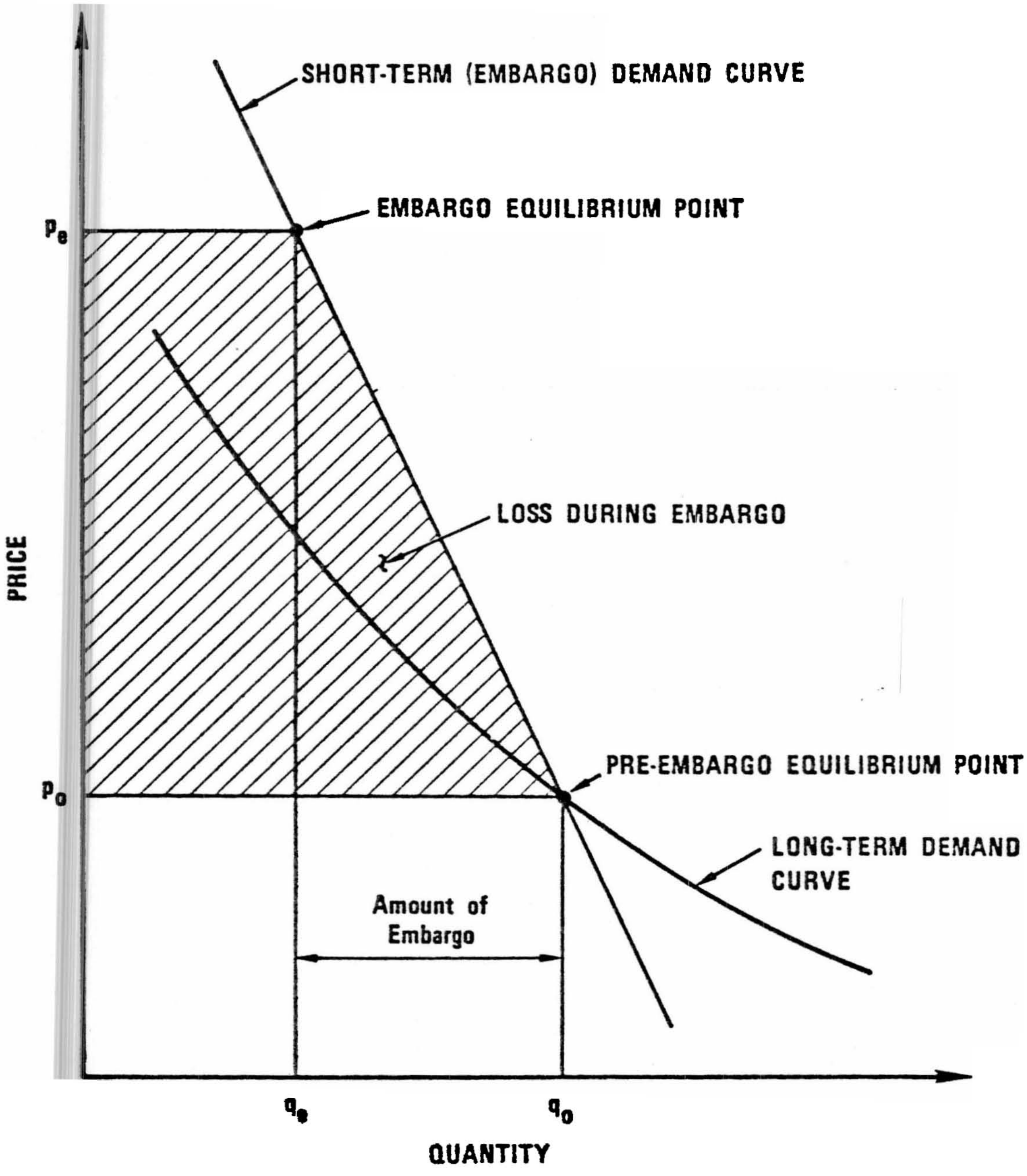


FIGURE A3 EMBARGO LOSS

the quantity of oil available for consumption decreases abruptly. Because of short-term inflexibilities in consumption patterns, the marginal value (or shadow price) of oil is much higher than the long-term demand curve indicates. A linear short-term demand curve was used to account for this effect. The economic cost of the embargo is the loss of consumer surplus during the embargo and is represented by the shaded trapezoidal area.

The synthetic fuels program, by replacing some of the imported oil, would reduce this embargo loss by increasing the amount of fuel available for consumption during the embargo. This reduction of embargo loss, weighted by the probability of the occurrence of an embargo, was credited to the program as a benefit.

Outcome Measures for Environmental and Socio-Economic Impacts. Non-economic costs of the synthetic fuels program include environmental damage and socio-economic disruption. These costs, to the extent that they are not internalized in the producers' costs (e.g., through pollution control costs), must be accounted for in evaluating program alternatives.

Categories of environmental costs include air quality, water quality, and disturbances to land and associated flora and fauna. Socio-economic impacts and health and safety considerations are other examples of social consequences that may not be included in the economic costs of synthetic fuels. For example, many of the synthetic fuels facilities may be built in sparsely settled regions, necessitating rapid creation of public services and other infrastructure, and perhaps involving social dislocation and conflicts in life-style between the incoming population and the present inhabitants of the region. Health and safety of the synthetic fuel process workers may also be considered a possible externality.

Outcome variables for environmental and socio-economic impacts were, thus, defined in four areas: air pollution (tons/yr NOx, SOx); water depletion (acre-ft/yr); water pollution (tons/yr disolved solids, suspended solids, and organics); land disruption (acres/yr); socio-economic impact ($/yr excess infrastructure, $/yr social maintenance, and population increase/yr); and occupational safety (deaths/yr).

DETERMINISTIC ANALYSIS

Figure A4 shows in flow diagram form major interactions relevant to the program decision. The government interacts with the synthetic fuels industry by receiving bids for constructing synthetic fuels plants and by accepting some of them. For those bids that are accepted, commercial demonstration plants are constructed, as represented by the "R&D, Commercialization" arrow in the figure. As a result of building and operating these commercial demonstration plants, the synthetic fuels industry acquires new knowledge regarding synthetic fuels processes. Such knowledge might include improved plant designs, measures for reducing capital and operating costs, improved efficiency, or decreased environmental impact. This learning is represented by the "Synfuels Technology" box. The synthetic industry interacts directly with the U.S. energy market through implementation of its technologies.

To capture the interrelationships represented in Figure A4, two models were integrated. A simple computer model was developed to calculate the net national benefit under each program alternative. To estimate energy supply and demand curves, the SRI National Energy Model was used (Cazelet 1977). Parametric demand curves derived from the Energy Model were used in the analysis to relate market price to the quantity of foreign and

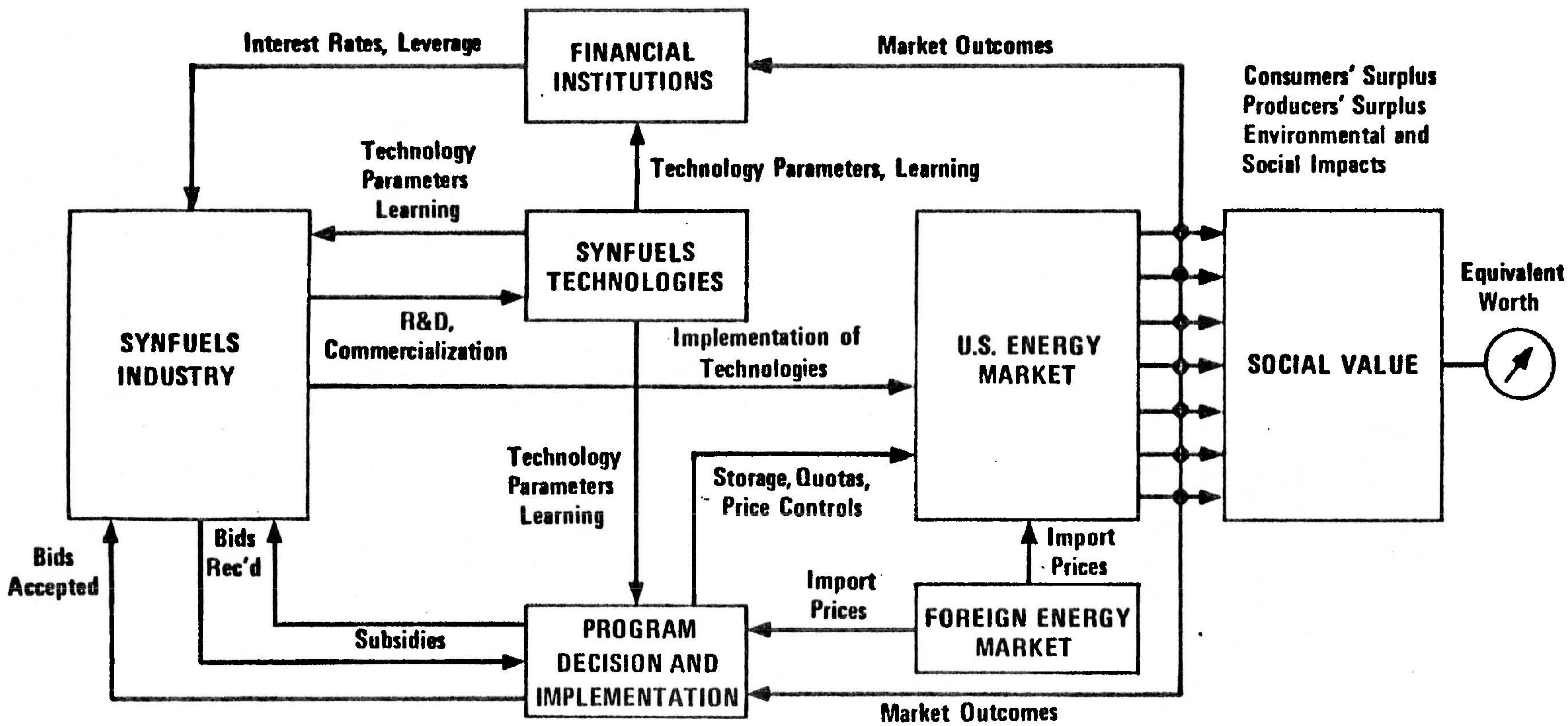


FIGURE A4 SYNTHETICS FUELS PROGRAM DECISION MODEL synthetic fuel demanded.

A number of simplifying assumptions were made in the model for calculating national net benefit. Figure A5 illustrates how the dynamics of the decision situation were represented. Time was divided into three discrete periods. The year 1985 was used to typify the decade of the 1980s and the year 1995 to typify the decade of the 1990s. In 1975, the government would make its program decision, choosing one of the four alternatives. All synthetic fuel plants built before 1985 were assumed to employ first generation technology. Therefore, the cost of synthetic fuel in 1985 was assumed to be independent of program size and to depend only on basic technological factors. By 1985, the program would have produced information useful for predicting the ultimate cost of synthetic fuels production. Based on this information and on the prevailing and projected price of imported oil, the industry would make its decision on further investment in synthetic fuel plants. The price of imported oil was assumed to depend on whether or not the oil producers' cartel remained effective in controlling prices. Plants built after 1985 were assumed to employ second-generation technology. Because of learning effects, the cost of production in these plants was taken to be lower than in the first-generation plants. The cost of synthetic fuel in 1995 was assumed to depend on the size of the commercialization program because larger programs would be likely to develop a low-cost technology available for second-generation plants. Finally, in the mid-1990s, when the new synthetic fuel plants would be on stream, the program impacts were assumed determined by the cost of synthetic fuels, the price of imported oil, which again depends on the current state of the cartel, and the U.S. energy supply and demand

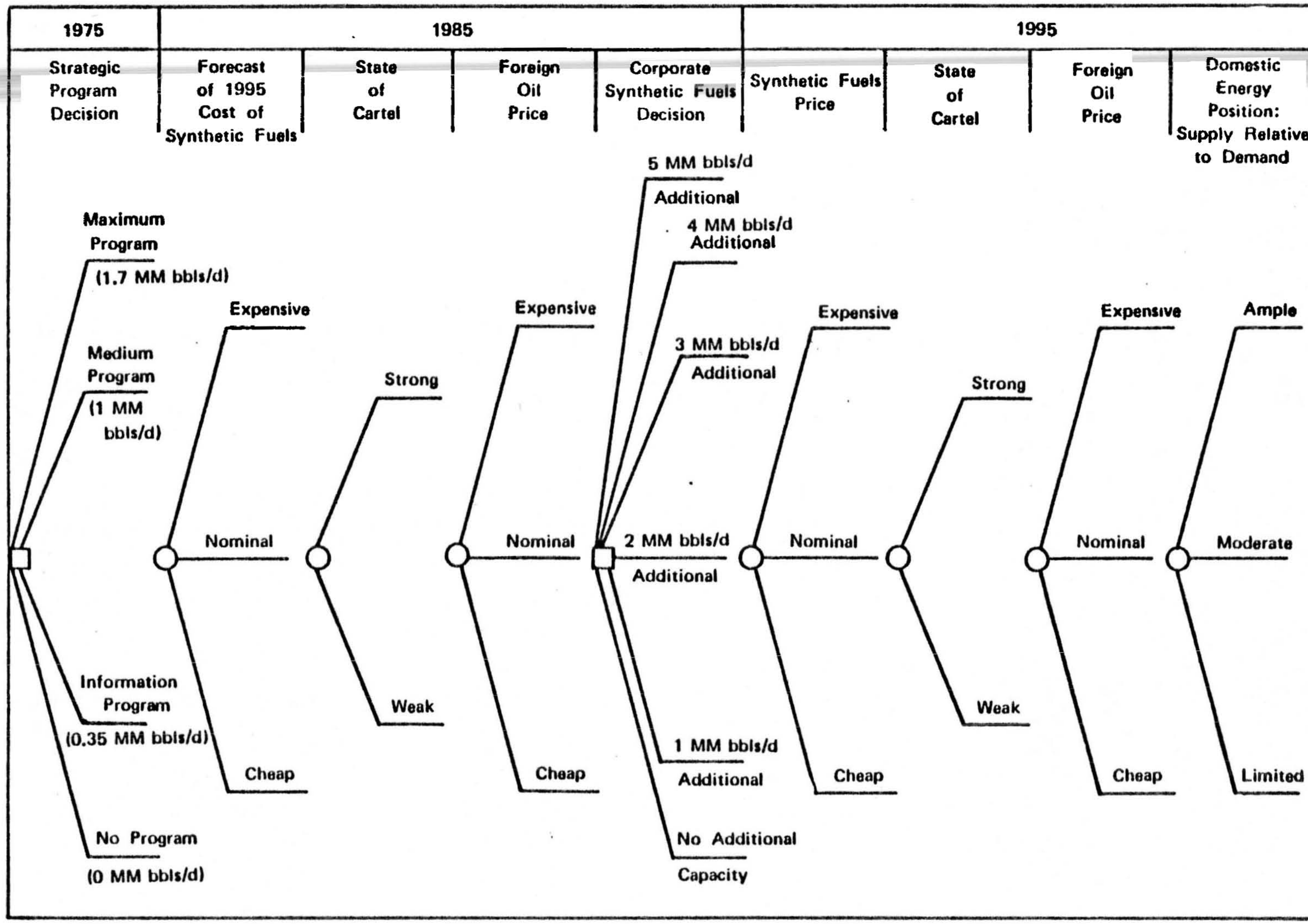


FIGURE A5 SYNTHETIC FUELS DECISION TREE

balance.

To simplify the social value model, environmental and social impacts were assumed proportional to the volume of synthetic fuel produced. Equivalent dollar values were then assigned to each occurance of each impact. Emission of sulfur oxides and nitrogen oxide were ascribed costs based on air pollution damages as cited in National Academy reports (NAS 1974, 1975). Increased salinity and other water quality issues were assessed in terms of dollars per acre-foot of water used. Land disturbance, including effects on vegetation and fauna and aesthetic impact, were included by assessing a dollar value per acre of disturbed land. Extrapolation from coal mining experience and standard assumptions for valuing fatal and nonfatal accidents provided the basis for assessing occupational safety costs.

Table A1 shows the dollar values in cents per barrel equivalent assumed for each of the environmental and social impact outcome variables. These value assignments result in an overall environmental and social cost of synthetic fuel production between $0 and $1.00/barrel, with a nominal estimate of $0.40/barrel. Aggregated program cost and benefits were measured in constant 1975 dollars and were discounted to 1975 using a discount rate of 10%.

PROBABILISTIC ANALYSIS

Uncertainty about each of the variables shown in Figure A5 was quantified in the form of probability distributions obtained in probability encoding sessions from experts selected by the President's Interagency Task Force. The decision tree was then used to incorporate these assessments into the analysis. For continuous variables, the probability distributions

Table A1

SOCIAL COSTS FOR REPRESENTATIVE SYNTHETIC FUEL TECHNOLOGIES
(Cents per Barrel Equivalent)

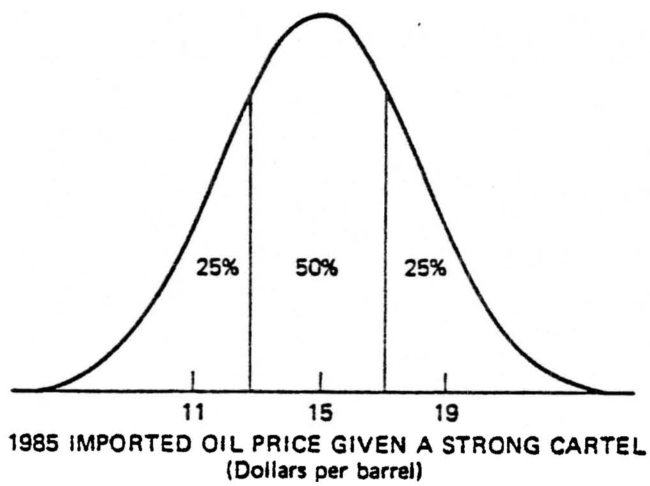
Category of Social Cost	Oil Shale			High Btu Gas Plant (Using Powder River Coal)		
	Low	Normal	High	Low	Normal	High
Environmental Costs						
Air Emissions						
Sulfur Oxides	1	8	21	5	19	47
Nitrogen Oxides	3	9	30	2	5	16
Water Depletion	0	1	13	0	3	42
Water Quality	0	2	23	1	11	56
Land Surface Alteration	0.1	1	11	0.1	1	8
Total* Environmental Costs	12	21	56	21	39	106
Socio-economic Impact	-14	7	70	-20	10	90
Occupational Health and Safety	6	12	30	0.3	0.6	5
Total* Social Cost	17	40	114	16	50	160
Values Used for Sensitivity Analysis:	0	40	100	0	40	100

*Totals for low and high cases are computed by taking the square root of the sum of the squares of deviations from nominal values.

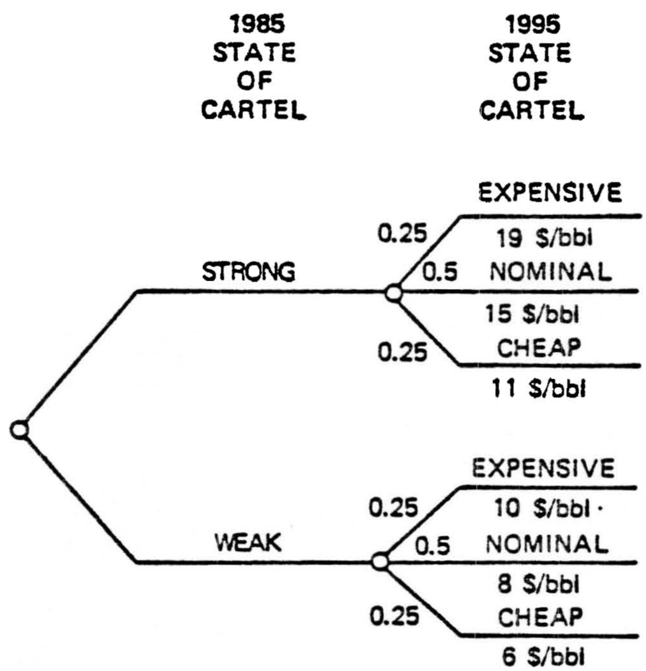
were discretized into three outcomes representing the 0.1, 0.5, and 0.9 fractiles of the probability distributions. Figure A6 illustrates the process for a variable with probabilistic dependencies.

The probability distribution shown in Figure A6(a) represents uncertainty in the 1985 imported oil price, given that the cartel is strong. According to this distribution, it is equally likely that the price will be above or below $15 per barrel (the median value). Also, there is a 10% chance that the price will be below $11 per barrel (the 10% fractile) and a 10% chance that it will be above $19 per barrel (the 90% fractile). The distribution was divided into three sections having areas of 25%, 50%, and 25%. The median value was used to represent the middle section, and the 10% and 90% fractiles were used to represent the two tails. Thus, as shown in Figure A6(b), the assessment was that there was a 25% chance that the 1985 imported oil price would be $19 per barrel, a 50% chance that it would be $15 per barrel, and a 25% chance that it would be $11 per barrel, given that the cartel is strong. The imported oil price, given that the cartel is weak was assessed to be much lower—$10, $8 and $6 per barrel, respectively.

Figure A7 shows the first three stages of the decision tree with probability assignments. Of particular interest are the assessments of the future state of the oil producers' cartel. As shown in Figure A7, the chances of the cartel remaining strong through 1985 were assessed by the Task Force to be 50-50. Given that it is strong in 1985, the probability that it would remain strong through 1995 was assessed to be 80% (not shown in the figure), whereas if it is weak in 1985, the chance that it would become strong by 1995 was assessed to be only 20%. Note that the complete



(a) Simple encoding technique



(b) Probabilities

FIGURE A6 ENCODING PROBABILITIES ON OIL PRICE

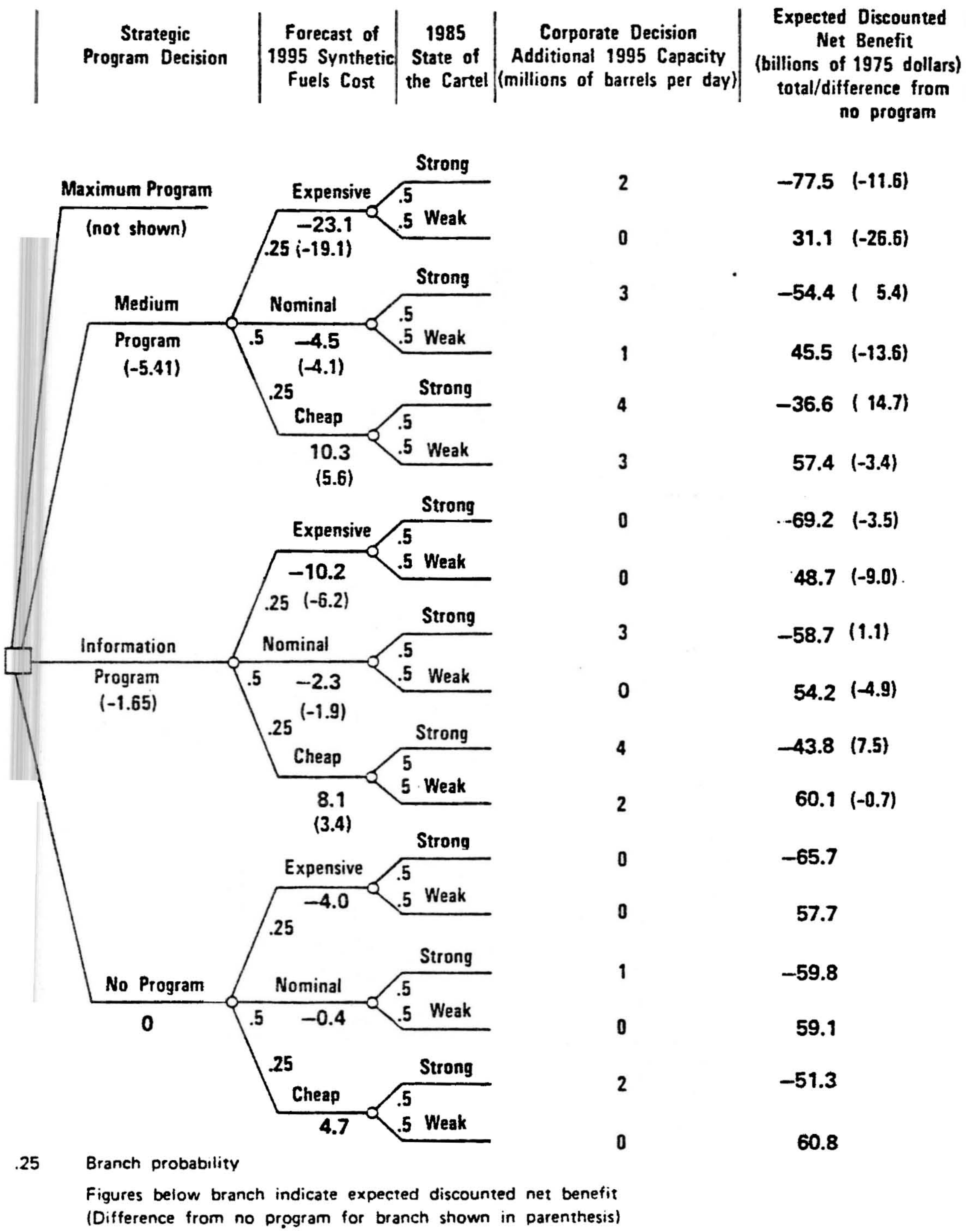


FIGURE A7 PARTIAL DECISION TREE DISPLAY OF RESULTS tree defines 5,832 different scenarios for each of the four program alternatives.

Analysis of the tree began by calculating the probability for each scenario (by multiplying the probabilities along each path) and the discounted net national benefit associated with it (using the computer model). Finally, for each alternative, the expected net benefit was calculated by weighting the outcome of each scenario by its probability and summing.

The industry decision in 1985 of how much further investment to make in synthetic fuels plants required special treatment. Although the government decision would be made on the basis of overall national benefits, the private sector decision would be made on the basis of corporate profits only. Therefore, in the analysis, the level of corporate investment that maximized expected future producers' surplus was selected (shown in Figure A7).

Figure A8 summarizes the results of analyzing the decision tree. The total expected discounted net benefit (in billions of 1975 dollars) is shown, along with its components, for each of the three synthetic fuels program levels relative to having no program at all. These results suggest that, on balance, the synthetic fuels commercialization program was not in the best national interest and that the bigger the program, the greater the national loss. The small informational program had an expected impact of minus \$1.65 billion. The larger program had expected impacts of minus \$5.41 billion and minus \$10.98 billion, respectively.

More insight may be obtained by looking at the components of total net benefit. Although the synthetic fuels program is expected to have positive

	Expected Discounted Net Benefit (billions of 1975 dollars)				
Program Alternative	**Consumer Surplus**	**Producer Surplus**	**Embargo Protection**	**Environmental and Socioeconomic**	**Total**
No Program	**0**	**0**	**0**	**0**	**0**
Information Program (0.35 mm bbl/day)	**1.07**	**-2.71**	**0.43**	**0.44**	**-1.65**
Medium Program (1 mm bbl/day)	**3.29**	**-8.74**	**1.18**	**-1.14**	**-5.41**
Maximum Program (1.7 mm bbl/day)	**4.55**	**-15.77**	**2.23**	**-1.99**	**-10.98**

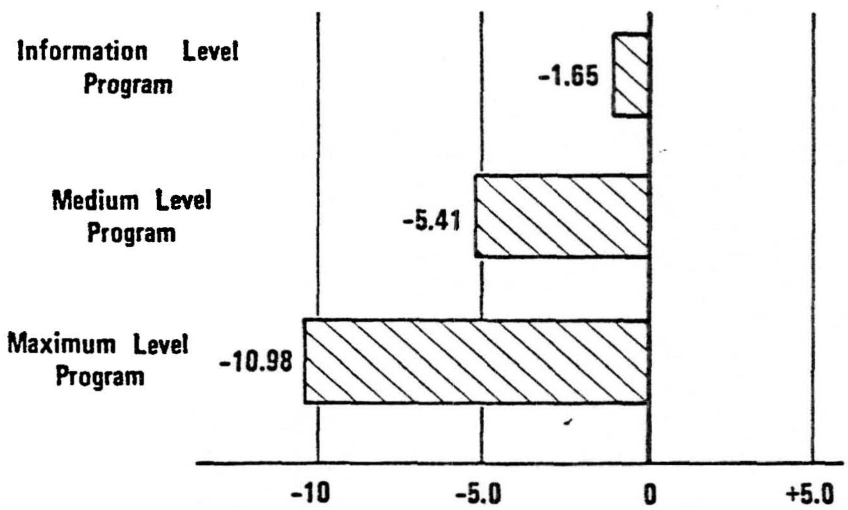


FIGURE A8 BENEFITS OF SYNTHETIC FUELS
PROGRAM ALTERNATIVES RELATIVE TO NO PROGRAM

impacts on consumer surplus through the possible moderation of future imported oil prices and on embargo losses through a slight reduction in oil imports, these benefits are far outweighed by the negative impact on producer surplus. Basically, it was far more likely than not that synthetic fuels would be more expensive than imported oil and therefore need a subsidy. The negative impact of environmental and socio-economic costs is relatively minor.

The results shown in Figure A8 are the expected values of program impacts. There is, of course, considerable uncertainty about the impact of the program, as shown in Figure A9. Although the expected impact of the informational program is $1.65 billion, there is a 30% chance that the net impact will be positive and a 10% chance that it will be as much as +$7 billion. On the other hand, there is a 10% chance that it will be as negative as -$9 billion. It is equally likely that the impact will be worse than or better than -$4 billion. The uncertainty in the impact of the larger program is even greater.

Figure A10 shows how two of the factors affect the results of the analysis. The -$1.65 billion expected impact of the information program consists of a 50% chance of -$4.86 billion if the cartel in 1985 is weak and a 50% chance of +$1.55 billion if it is strong. Note that a weak cartel, which leads to generally lower imported oil prices, is bad for the synthetic fuels program, but presumably very good for the nation as a whole. Conversely, a strong cartel, with higher imported oil prices, makes the program look good, but is bad for the nation. This emphasizes that the synthetic fuels program is a hedging strategy--it pays off when other things are going badly. Note also that if the cartel is weak, the program

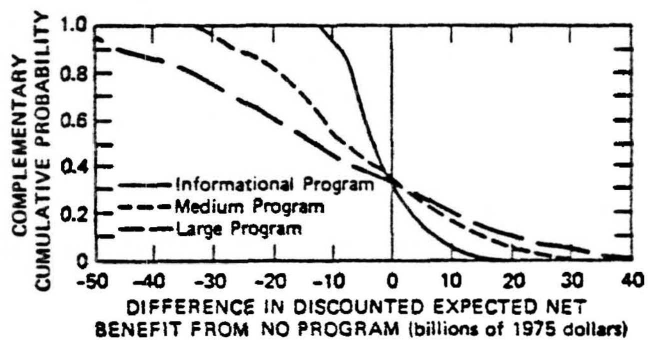


FIGURE A9 UNCERTAINTY IN PROGRAM IMPACTS

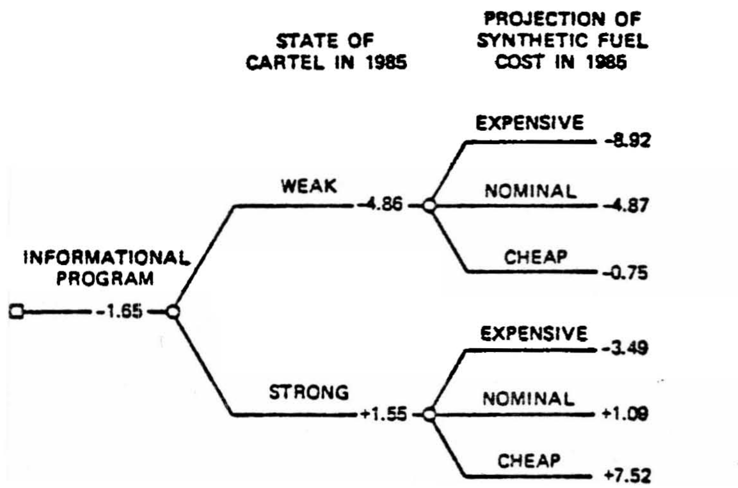


FIGURE A10 PARTIAL EXPANSION OF TREE

looks bad even if synthetic fuels turn out to be cheap to produce. On the other hand, if synthetic fuels turn out to be expensive, the program looks bad even if the cartel is strong. That is why, on balance, the program looks bad.

So far, the analytic results have been presented only in terms of expected values. It might by argued that the decision should not be made on the basis of expected values but rather on the basis of values that are adjusted for risk. To show how various levels of risk aversion would affect the results, the risk sensitivity profile shown in Figure A11 was constructed. To obtain Figure A11, it was assumed that the nation's risk attitude may be expressed by one of the family of exponential utility curves. The degree of risk aversion expressed by this curve is given by one parameter: risk tolerance. The smaller the risk tolerance, the greater the degree of risk aversion.

Figure A11 shows the value to the nation of each program level relative to no program as a function of the nation's risk tolerance, assuming an industry risk tolerance of $5 billion for the private sector capacity expansion decision. Note first that the value of the program increases as the nation's risk aversion increases. This is characteristic of a hedging strategy, because it reduces overall uncertainty. However, the nation's risk tolerance must be less than $67 billion for the information program to be better than no program and it must be less than $56 billion for the medium size program to be the best alternative. We believe that a reasonable range for the nation's risk tolerance is from one-fourth to one-half of annual GNP, or about $300 billion to $600 billion. As Figure A11 shows, for any risk tolerance in this range, the

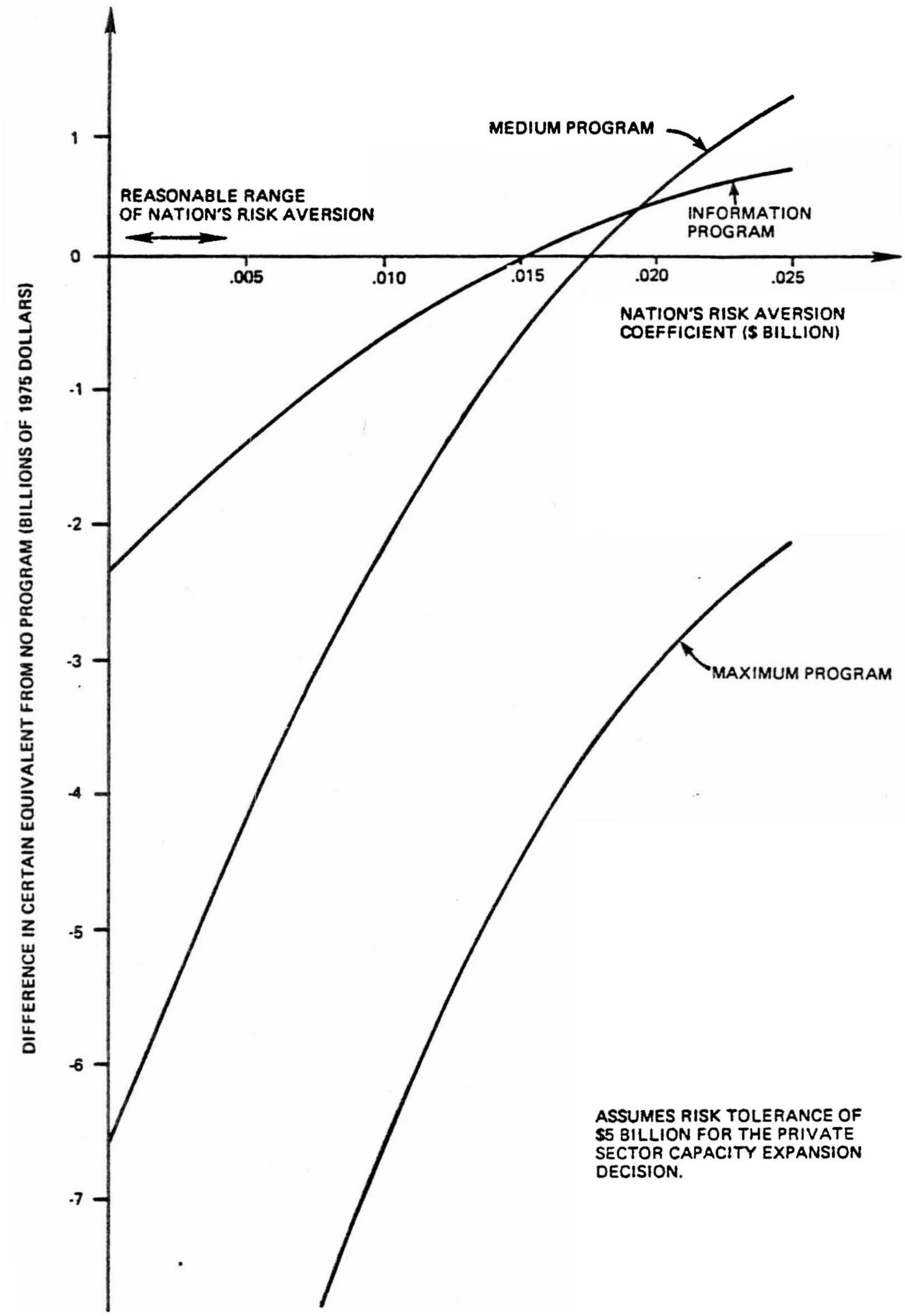


FIGURE A11 SENSITIVITY TO GOVERNMENT RISK AVERSION ranking of program alternatives was the same as in the expected value case, with the best alternative being no program at all.

INFORMATIONAL ANALYSIS

A formal calculation of the value of obtaining additional information was not conducted in this analysis. Instead, to measure the relative importance of the various uncertainties, sensitivity analysis was used. The sensitivity analyses were conducted by observing the effects of changing probability assignments. One such sensitivity is to changes in the probabilities of the oil producers' cartel being strong or weak through 1985, which is shown in Figure A12.

The figure shows the expected net impact of each program level relative to no program as a function of the probability of a strong cartel in 1985. It assumes that with 80% probability, the cartel will remain in the same state from 1985 to 1995. The figure shows that only if the probability of a strong cartel in 1985 exceeds 75% does the information program look better than no program and that the probability must exceed 82% for the medium size program to be the best alternative. An interesting result is that the maximum size program is never optimal for any value of this probability.

Sensitivity analyses showed that the key uncertainties affecting the synthetic fuel decision were the expected strength of the cartel, the cost of synthetic fuels technology, and the domestic energy position in 1995 with respect to imports.

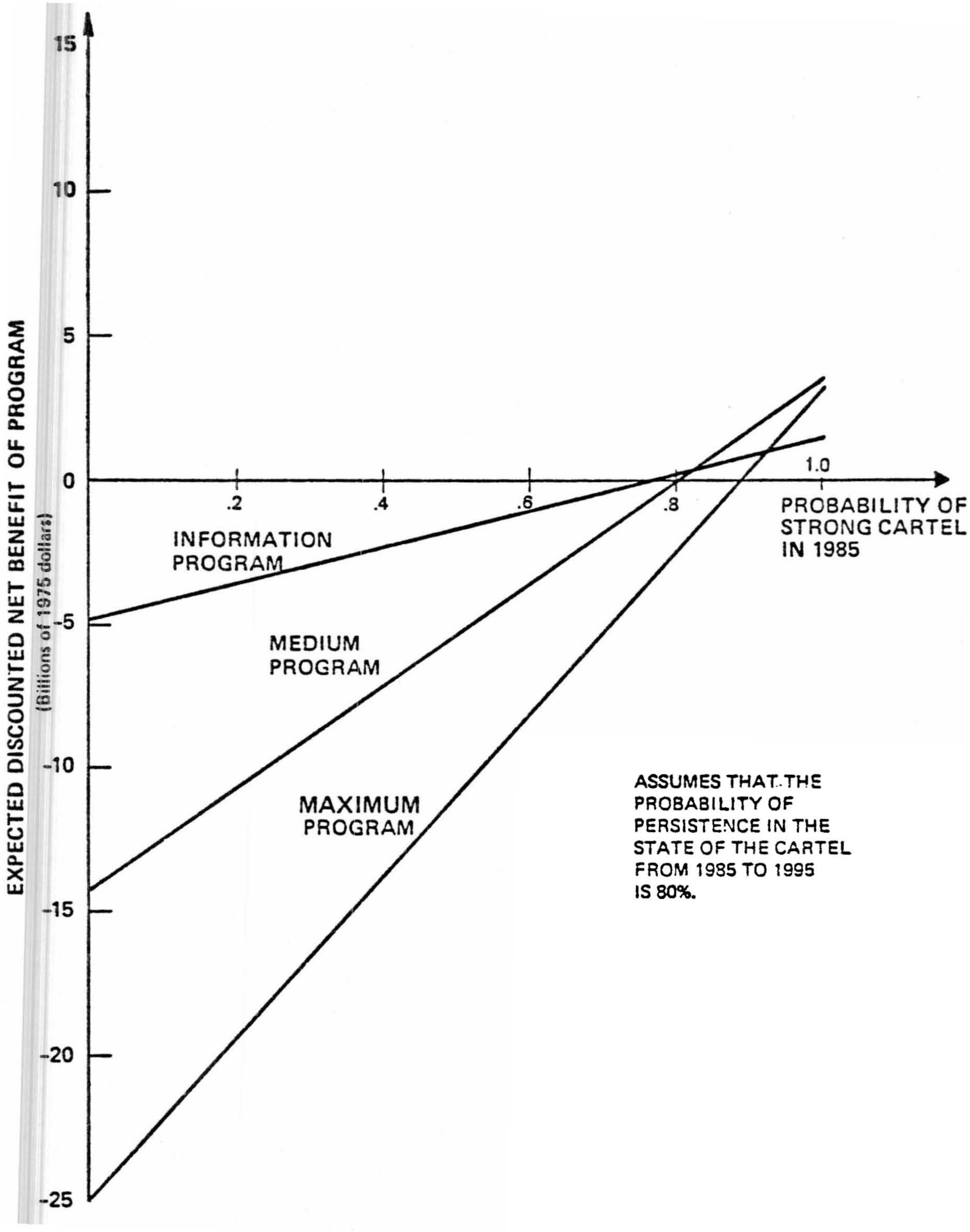


FIGURE A12 SENSITIVITY OF EXPECTED NET BENEFIT TO THE PROBABILITY OF A STRONG CARTEL IN 1985

POLICY EVALUATION

As far as we can determine, this was the first decision analysis to be presented in the White House. The chairman of the Task Force presented it to the President's Energy Resources Council in July 1975 (Synfuels Interagency Task Force 1975). Citing benefits of the program that were not quantified in the analysis, such as the international leverage gained by the United States in asserting positive leadership in developing alternate fuel sources, as well as the "relatively small risk and expected cost" of the small program, the Task Force recommended that the government undertake the informational program alternative with a possibility that it could switch to the medium size program pending additional information on crucial factors. This illustrates a situation in which factors that were felt not to be adequately captured by the analysis were intuitively integrated with analysis results to arrive at a policy recommendation. The Administration's bill incorporating this recommendation ultimately failed to pass through Congress.

Appendix B

REVIEW OF SELECTED OTA STUDIES

As part of this effort, several completed OTA studies were reviewed to investigate the extent to which the methodology described in the main body of this paper is currently being used by OTA. The studies reviewed were "Energy from Biological Processes" (July 1980), Technology and East-West Trade" (November 1979), and "The Implications of Cost-Effectiveness Analysis of Medical Technology" (August 1980). Due to time and resource constraints, the reviews consisted of little more than a quick reading of the final reports produced under each study. Consequently, conclusions expressed in this appendix must be interpreted with caution, as they are based on only a superficial understanding of the methodologies applied in the OTA studies. In particular, there is the possibility that statements concerning analysis that was omitted in the studies may reflect more the present author's misunderstanding than actual limitations of the OTA studies.

Table B1 summarizes our estimates of the extent to which each of the reviewed studies incorporated various elements of the decision-focused TA methodology. Seventeen elements of the methodology have been identified and are listed along the left hand side of the table. Each cell in the table is labled with a Y, P, or N, according to whether the corresponding study appears to have applied that element, only partially applied that element, or does not apply that element of the methodology. Some brief comments concerning each of the studies appear in the paragraphs below.

Table B1

EXTENT TO WHICH THREE OTA STUDIES EMPLOYED
ELEMENTS OF THE DECISION-FOCUSED TA METHODOLOGY

Elements of Decision-Focused Technology Assessment	Energy from Biological Processes	Technology and East-West Trade	Cost-Effectiveness of Medical Technology
Problem Definition			
Problem bounding determined by decisions to be made	P	P	N
Alternative future macroenvironments considered	P	N	P
Alternative technological implementations considered	Y	P	N
Alternative Generation			
Identifies specific decisions, decision-makers, and alternatives	Y	Y	P
Strategic alternatives defined for analysis	P	Y	P
Relevant outcome variables defined	P	N	N
Deterministic Analysis			
Comprehensive, quantitative structural model constructed	P	N	N
Explicit social value model constructed	N	N	N
Sensitivity analysis conducted to identify crucial uncertainties	P	N	N
Probabilistic Analysis			
Crucial uncertainties quantified using probabilities	N	N	N
Uncertainty in outcomes of policy alternatives quantified	P	N	N
Risk sensitivity/risk aversion measured	N	N	N
Informational Analysis			
Value of eliminating crucial uncertainties estimated	N	N	N
Value of specific information gathering alternatives calculated	N	N	N
Analysis iterated to incorporate new information	P	N	N
Alternative Evaluation			
Consequences of policy alternatives estimated quantitatively	P	N	N
Assumptions/approximations potentially affecting results clearly stated	P	P	P

KEY: N = Not accomplished to any significant degree by the assessment.
P = Only partially accomplished.
Y = Completely or nearly accomplished.

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U.S. Office of Technology Assessment, "Technology and East-West Trade," Washington, D.C. (November 1979).

REVIEW 1: ENERGY FROM BIOLOGICAL PROCESSES

Although none of the studies developed a formal decision model as part of the assessment, this study came closer to the process described in this paper than did the others. Specific strategic policy options for promoting energy from biomass are clearly defined, and the approach applied seems to be consciously designed around an investigation of these alternatives. At least one important aspect of the problem was explored through the development and analysis of a quantitative model (an economic model used to identify the production level at which energy uses of American grain harvests will begin to push up grain prices). The importance of uncertainty was investigated through sensitivity analysis using alternative supply assumptions. Although critical uncertainties were not quantified with probability distributions, uncertainty in energy produced was reflected by estimating a range of possible outcome values.

Construction of a simple, but comprehensive decision model might have permitted the study to derive additional insights through deterministic, probabilistic, and informational analysis, as described in the body and illustrated in Appendix A of this report. Of particular interest would be estimates of the value of additional information. For example, how much would it be worth to reduce uncertainty in future world demand for food or to have better information on the technical feasibility of developing a low cost, small-scale, conversion facility. Knowledge of the value of such information might be useful in setting research priorities.

REVIEW 2: TECHNOLOGY AND EAST-WEST TRADE

This is a very thorough and exacting study of the controversy of selling United States technology to the Communist world. The authors appear to do an excellent job of defining strategic policy options, including identifying individual decisions for implementing each strategic policy. The TA, however, does not (and did not intend to) evaluate alternative policy options. The authors state, "It was the goal of this assessment to present...points of view as clearly as possible...providing material that will allow a better analysis of the kinds of military, political, and economic costs and benefits that any program affecting East-West trade and technology transfer is likely to incur."

The results of the study appear to provide an excellent starting point for a more formal analysis of the type described in the paper. It has been our experience, however, that such background studies can be conducted more efficiently and are likely to provide more support to formal policy analysis if conducted as part of an iterative model building exercise. With such an approach, a highly simplified pilot model would be constructed by carrying out one cycle of the decision-focused TA process. Because of the complexity of East-West technology transfer, the pilot model clearly could not be relied upon to estimate the costs and benefits of alternative policies with any accuracy. However, sensitivity analysis of even the simple pilot model would probably demonstrate some of the basic conclusions, such as the low probability that any of the policy options would materially affect U.S. balance of trade in the short run. Sensitivity analysis and value of information calculations on the pilot model could then be used to set priorities and help direct the major information and issue clarification effort so as to provide information directly relevant to the analysis of alternative policies.

REVIEW 3: COST-EFFECTIVENESS ANALYSIS OF MEDICAL TECHNOLOGY

This study correctly identifies many of the faults typically appearing in cost-effectiveness analysis and cost benefit analysis (CEA/CBA), such as the tendency to ignore uncertainty and to present CEA/CBA as an alternative to the human decision-making process rather than as a device to structure and provide insights to decision makers. I suspect, however, that there are knowledgeable practitioners of CEA/CBA that would argue that many of the faults are symptoms of poor applications rather than inherent weaknesses. For example, there are a number of recent examples of CBA studies that use probabilities to explicitly incorporate uncertainty in a manner similar to that prescribed by decision analysis.*

The intent of the study appears to be to support policy making. The authors state, "To aid in their decisions concerning the possible use of CEA/CBA in Federal health programs, the Senate Committees on Labor and Human Resources and on Finance asked OTA to explore the applicability of CEA/CBA to medical technology." The results of the study would probably more effectively meet this objective if some of the basic elements of the decision-focused TA methodology had been applied. In particular, it would be useful to (1) identify and characterize the alternatives to CEA/CBA

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*Although CEA/CBA and decision analysis appear similar in their formalism, they differ fundamentally both in goal and in detail. CBA is a much older technique that emerged from applications of economic theory. Whereas CBA focuses on creating a quasi-objective representation of the real world, decision analysis is directed toward producing an aid for decision makers. For a clear description of the distinctions between CBA and decision analysis, see (Watson 1980).

(e.g., the methodologies that are currently being used) for medical technology decisions, (2) establish a consistent set of outcome measures to evaluate these alternatives, and (3) analyze the extent to which each alternative achieves the desired objectives. Such an approach would likely be of greater usefulness to policy makers interested in whether greater use of CEA/CBA would improve or impair medical technology decision-making.