The Value of Climate Information

Stanley R. Johnson and Matthew T. Holt

Staff Report 86-SR 6
March 1986

The Value of Climate Information

by

S. R. Johnson and Matthew T. Holt*

Staff Report #86-SR6

Center for Agricultural and Rural Development
Iowa State University

March 1986

Paper presented at the Seminar on the Policy Aspects of Climate Forecasting, jointly sponsored by the National Climate Program Office, NOAA, and the National Center for Food and Agricultural Policy, RFF, March 4, 1986, at the National Academy of Sciences, Washington, D.C.

*The authors are Professor of Economics and Administrator, and Temporary Instructor, Center for Agricultural and Rural Development, Department of Economics, Iowa State University, Ames, Iowa 50011.

THE VALUE OF CLIMATE INFORMATION

S.R. Johnson and Matthew T. Holt

Introduction

The existing system for sensing, recording, and reporting climatic conditions has been developed mainly in response to demands of specific clients. Weather conditions provided for airline navigation, agricultural production management, and severe storm tracking, are three examples. Thus, the system for producing, storing, and disseminating climate data has strong historical linkages to the demands of major clients and the sensing and recording technologies available at the time of implementation. Locations of first order stations at airports, the cooperator system, frequency of reporting, and the levels in the atmosphere at which data are recorded all can be viewed as having a user based history.

With the advent of new sensing, recording, and reporting technologies, and changing needs of existing clients and the entry of new clients, there has been a continuing effort to justify economically the system supplying these services. Climatic data are produced by the public sector and made available at a highly subsidized user cost: that is, the data are public goods. To provide an economic rationalization for the production and dissemination system, it must be shown that the rate of return, or benefit relative to cost, is consistent with that available from alternative employment of societal resources. For this calculation, the relevant cost and benefit concepts are, of course, social.

The effort to justify economically the climate information system has resulted in a number of research activities and suggested organizational changes. One way to value the climate information system would be to make it private in some way. This alternative would produce the service in such a way that the market would automatically determine the value and allocate resources. This approach to valuation and resource allocation has recently received increased attention as indicated by the initiation of user charges for certain types of weather information and related services. Although still at a preliminary stage, this approach to organizing the production and delivery system can be viewed as "testing" the market for these services.

It is, however, important to recognize the market may not be efficient in valuing climate information or allocating resources. Climate information is a non-rival, non-excludable commodity. That is, two or more consumers can simultaneously use the same "unit" of climate information (non-rival) and it is not, in general, possible to prevent certain groups or individuals from using available climatic data (non-excludable). The implication is that the market equilibrium is not optimal since the economic externalities of climate information are not incorporated into individual decision-making. Theoretically, either an artificial market must be established (i.e., a system that artificially assigns property rights for climate information) or a socially optimal tax-subsidy scheme must be implemented if an efficient resource allocation to the climate information system is to be attained (Malinvaud 1971). Hence information obtained from testing the market must be viewed cautiously as an input to the design of a socially optimal climate information service.

To compliement the market experiments, research has been undertaken to develop more formal valuations of the climate information system. This research is generally conducted in one of two primary areas. The first area is related to determining the value of climate services, or specific components of those services, for both individual decision-making units and society as a whole. This applied research is carried out with the goal of actually assigning monetary values to the components of the climate information studied. Applied studies of information value at the individual decision level are the most numerous and the most cogent. The second area of research has focused on developing appropriate methods for estimating individual and societal values of climate information services, as well as the appropriate methods for their measurement.

The present paper has the objective of reviewing the progress that has been made in valuing the climate information system. First, selected concepts from the economics of information are reviewed. The intent is to provide a general framework for analyzing the valuation methods currently employed. Then, selected studies which have estimated the economic value of particular components of the climate information system are discussed. Of concern are both the method of valuation and the results. This exercise--comparing the valuation theory with applications for the climate information system-- raises a number of questions. Important issues posed by the questions pertaining to design of valuation studies, privatization, and resource allocation are then examined. Finally, a few observations are provided on the progress in valuation methods and the potential for new analyses to improve the basis for designing and organizing the climate information system.

Economics and the Value of Information

The economic theory of information value has progressed significantly in recent years. With the development of the von Neumann-Morgenstern utility hypothesis, and the refinement of decision theory under uncertainty (Arrow 1965; Pratt 1964), the integration of information theory into the mainstream of economic thinking has occurred rapidly. In short, the development of uncertainty theory has provided a basis for reconciling a number of important issues related to the value of information in society, investment in the production of information, impacts on price determination, relationships between information and prices, etc. (Fama 1970; Grossman and Stiglitz 1976; Gould 1974; Hayek 1945; Hess 1982; Hirshleifer 1971; Kunkel 1982; Marschak 1971; McCall 1965; Riley 1979). Two surveys of information theory which provide an integration and synthesis of available results are by Hirshliefer and Riley (1979) and Stigler (1961). The present discussion will review key concepts from the theory which will be helpful in interpreting the available empirical results on the value of climate information and suggest a possible framework for improving the generality and scope of future investigations.

Information and Individual Valuation

The approach in modern economic theory is to view information as a factor in the decision process which can be used by individuals to reduce uncertainty. A stylized individual decision model illustrating the central concepts of the theory can be developed as follows. Subjective probability is the key to the theory (von Neumann and Morgenstern 1944). Consider a set of actions $a = (1,\ldots,N)$ and a set of possible states of the world $s = (1,\ldots,M)$. Consequences of these actions and states of the world $c(a,s)$ are all presumed known to the individual. Furthermore, the individual is assumed to have the ability to rank the possible consequences of each action according to relative desirability. That is, the individual is assumed to have a preference relation $v[c(a,s)]$ defined over the set of possible actions and consequences. The uncertainty is related to the probability of realizing the various states of the world. Let the subjective probabilities for the individual be denoted by p_s. The individual is assumed to have a prior probability distribution on the possible states of the world. The decision problem then is

(1) $$\max_a E[u(a,s)] = \sum_s p_s \, v[c(a,s)]$$

where E[u(a,s)] is expected utility of the individual decision maker. Note that if the decision maker is risk neutral, the utility maximization problem is equivalent to choosing the action which maximizes the expected value of the consequences. This, of course, follows from the fact that marginal utility is constant in the risk neutral case, irrespective of the level of income. The individuals subjective probability distribution on the states of the world can be modified by the acquisition of information. Information can be viewed as a set of possible messages. These messages, denoted i=(1,...,I), provide the basis for revising the probabilities associated with each state of the world. This revisions process may, in turn, lead to a different choice of action. Observe, however, that the decision maker does not know in advance which of the possible set of messages will be received. This, in turn, implies that the decision maker must determine a subjective probability q_i of receiving message i. The probability q_i is in turn related to the conditional probabilities or likelihoods $q_{i,s}$ of receiving message i in each state s and is determined by

(2) $$q_i = \sum_s q_{i,s} \, p_s$$

where p_s represents the previously defined subjective probability associated with state s. Bayes' Theorem, in combination with the message probabilities defined in (2), provides a basis for revising the probabilities attached to each state of the world. More specifically, after receiving message i, the decision maker can determine the posterior probability of state s given message i by

$$(3) \qquad p^*_{s,i} = \Pr(s\ i) = \frac{\Pr(i\ s)\ \Pr(s)}{\Pr(i)} = \frac{q_{i,s}\ p_s}{q_i}$$

Figure 1 provides an illustrative example of a Bayesian revision for the case of continuous s. The likelihood function shows the probability of receiving message i given state s (i.e., $q_{i,s}$). The prior probability distribution defines the unconditional probabilities p_s associated with state s before the message i has been received. Notice that initially the individual believes that relatively higher values of s are more likely, as indicated by the position of the prior distribution. However, the likelihood function shows that the probability of receiving message i is higher for relatively low values of s. The revised or posterior probability distribution then represents a composite of the prior distributoin and the likelihood function as determined by Bayes' Theorem in (3). It is clear from (3) that the more certain the prior beliefs, the more closely the prior distribution will resemble the posterior distribution irrespective of the values of q_i and $q_{i,s}$. Intuitively, this suggests that the greater the level of initial confidence pertaining to a particular state s, the lower will be the value the individual attaches to receiving message i.

Values of additional or new information (i.e., the message) are based on the difference in the expected utility from the more informed decision compared to the expected utility without the information. This difference in expected utility, given the usual regularity conditions on the utility functions, can be written as

$$(4) \qquad V_i = E[u(a_n, p^*_{s,i})] - Eu(a_0, p_s).$$

The information decision problem for the individual decision maker is then one of comparing the two choices, a_o and a_n. Under the first choice, a_o, the

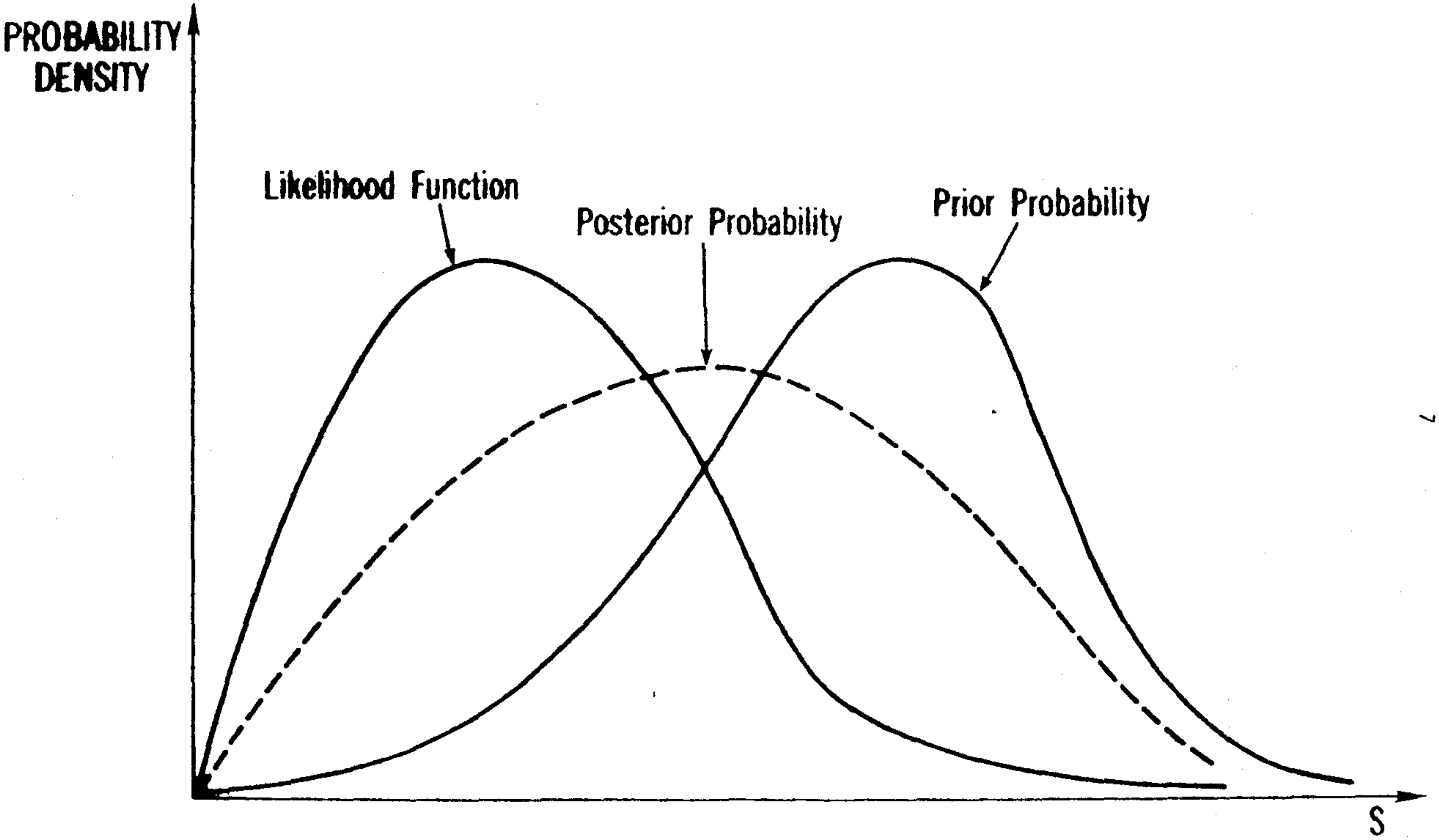

Figure 1. Illustrative Bayesian Probability Recalculation.

information or message i has not yet been received. Under the second choice, a_n, the information has been received and processed in accordance with (3) to form $p^*_{s,i}$.

Observe that this illustrative valuation problem is <u>ex post</u> in nature. That is, the valuation of information is made <u>after</u> the message has been revealed. While this simplified version of the information decision problem is useful and, in fact, characterizes much of the empirical work on information valuation at the individual level, it is stressed that the problem is not yet formulated as usually perceived by the decision maker. The information decision as typically encountered is an <u>ex ante</u> problem.

To formulate the <u>ex ante</u> information valuation problem, consider the decision of the individual about additional or new information. The individual in this circumstance would not know in advance the message to be obtained. To simplify, assume that the individual purchases the information from a vendor. Alternatively, this information could be provided by a public agency. If the information has no cost, then the value of the information can be characterized by

$$(5) \qquad V^* = \sum_i q_i[u(a_i, p^*_{s,i}) - u(a_o, p^*_{s,i})] = E(V_i),$$

where the probability distribution, as indicated by the expectation, reflects the uncertainty about receiving message i. Thus, the decision problem in this extended context is one of summing or integrating over the possible messages and associated probabilities.

Information and Market Valuation

While the decision problem for the individual can be developed, at least in principle, straight forwardly, the market determination of information value is much more difficult. Two issues complicate the market valuation problem:

1) the equilibrium condition for the market and how this equilibrium condition is modified by the introduction of additional information and

2) the aggregation of individual responses to produce the market level supply and/or demand functions used in establishing economic value.

Of course, the ex ante-ex post decision problem still remains (Choi and Johnson 1986).

Recent developments in rational expectations theory provide a tractable way of closing models and determining market implications when participants make decisions with imperfect information. Essentially, the rational expectations hypothesis implies that individuals understand the basic structure of the market in which they participate and act on that information (Muth 1961). Of course there are other expectations theories. The rational expectations approach is useful as a benchmark against which to compare results of other expectations hypotheses and attractive for its consistency with the other behavioral assumptions included in the model specification (i.e., expected utility maximization, etc.).

The results on closing models with rational expectations and developing appropriate microfoundations for market equilibria when market participants face uncertainty have only been recently developed (Newberry and Stiglitz 1981, Wright 1979). Many of these which have applied the rational expectations model have evaluated stabilization policies in competitive markets. They show that the benefits of intervention in competitive markets result from the more stable environment provided for producers and/or consumers. A modest extension of these results is to consider market intervention through added information about uncertain events, even if at a cost to the participants.

To illustrate the above concepts, consider a simple case in which N identical producers of a homogenous commodity face a random demand schedule. The producers are presumed to make production decisions _ex ante_, before the "realized" demand schedule is observed. The number of market participants is also assumed large enough that the industry can be considered competitive. If q represents the output of a single producer, then Q=Nq is industry output. A general representation of the stochastic market demand function is given by

$$P = P(Q,\mu), \ \partial P/\partial Q < 0 \tag{6}$$

where μ is a random variable with distribution function $G(\mu)$. For a given level of market output Q, the distribution function $G(\mu)$ completely determines a price distribution $F(P|Q)$ and an expected inverse demand function

$$\overline{P}\ (Q) = \int_0^\infty P dF(P|Q) = \int_{-\infty}^\infty P(Q,\mu)\ dG(\mu). \tag{7}$$

In previous studies the risk averse producer has been assumed to have a subjective distribution $F^e(P)$ of possible price outcomes (Baron 1970; Sandmo 1971; Leland 1972). In the present model, the rational expectations hypothesis is used to argue that the distribution $G(\mu)$ ultimately becomes known to producers. That is, once producers make a subjective estimate Q^e of industry output Q, the subjective distribution $F^e(P) = F(P|Q^e)$ is completely determined.

Given the subjective price distribution $F^e(P)$, a producer will maximize expected utility of profit

$$EU(\pi) = \int_0^\infty U[Pq - c(q)]\ dF^e(P) \tag{8}$$

where $U(\cdot)$ is a von Neumann-Morgenstern utility function and $c(q)$ is an appropriate cost function. Since the producer's optimal output q^* depends on the subjective estimate Q^e, we can write optimal output as $q^* = q^*(Q^e)$. Thus, industry output can be expressed as

$$Q^* = Nq^*(Q^e) = H(Q^e). \tag{9}$$

The rational expectations hypothesis as used in this simplified context implies that firms' subjective price distribution $F^e(P)$ will equal the actual price distribution $F(P)$ (Choi and Johnson 1986). Of course, at the end of the period when market demand is realized, producers only observe the actual market price and not a distribution. An important feature of the present model is that firms can verify <u>ex post</u> the rationality of their production decisions by comparing Q^e with Q. Since $F(P\ Q^e) = F(P\ Q)$ if and only if $Q=Q^e$, the rational expectations hypothesis implies that market equilibrium occurs only when actual and anticipated output are equal.

The above framework can be applied for investigating the market valuation of information. As Chavas and Johnson (1983) point out, a number of interesting parallels exist between information theory and the formation of rational expectations. The exact nature of the linkage depends on the amount of information available and its cost at the time the firm makes production decisions. With additional information, producers could revise their subjective estimates of the price distribution $F^e(P)$, as well as their subjective estimates of all relevant distribution parameters. Additional information should, in general, improve resource allocation and enhance market efficiency. However, even if additional information did nothing more than bring about a change in dispersion without changing the mean of the distribution (Rothschild and Stiglitz 1970), we would still expect different market results. The reason for this is that any change in the dispersion parameter of $F^e(P)$, even if the centrality parameter remains unchanged, will affect optimal output decisions for expected utility maximizing producers.

Clearly, many refinements and extensions can be made to the above model. The simplified model is included only to suggest the complexity of the market valuation problem. For instance, the model could be extended to include a stochastic production process. In this case, q becomes a random variable with a distribution conditioned on the level of the inputs. Producers would then employ rational expectations to determine subjective estimates of the joint distribution of P and Q. Not only does the rational expectation approach have important implications for estimating the market value of information, but it also raises unsettling questions about conventional valuation theory and the empirical methods presently employed in estimating market relationships from _ex post_ or observed market outcomes for use in valuation exercises.

Only recently has it been recognized that the usual producer surplus measures are inappropriate gauges of welfare under uncertainty (Pope et al. 1983). By employing the above market equilibrium mechanism and the appropriate microfoundations, the information valuation problem can be addressed more systematically. The _ex post-ex ante_ problem still remains, however. Most of the surplus measures used in economic theory of value are _ex post_. Recently it has been shown that these concepts must be modified if the information valuation problem is viewed _ex ante_ (Choi and Johnson 1986).

More specifically, three commonly applied welfare measures are Marshallian consumer's surplus and compensating and equivalent variations.

Marshallian consumer's surplus is simply the area under the demand curve and will be explained more fully in the subsequent section. Compensating variation is defined as the additional income necessary, after a price change, to restore an individual to the original level of well being before the price change. Equivalent variation is the amount of income necessary, after a price change, to restore the individual to the original level of utility, assuming that the initial price still holds. The distinction is that compensating variation uses an "after-price change" base while equivalent variation uses a "before-price change" base. Willig (1976) has illustrated under very general conditions that Marshallian consumer's surplus closely approximates compensating variation. This fact, coupled with ease of application, has resulted in the continued use of Marshallian surplus measures in empirical valuation studies (Hayami and Peterson 1972).

An additional complication arises, however, if price is a random variable. The most common approach in this instance is to recognize that the surplus measures are also random variables and that their expectations will provide an indication of average benefits accruing to an individual (Waugh 1944). Recently though it has been shown that these concepts must be modified if the information valuation problems is to be viewed ex ante. In particular, it has been demonstrated that expected Marshallian consumer's surplus (and, consequently, expected compensating variation) is a valid welfare measure only in the special case when marginal utility of income does not depend on price (Turnovsky, Shalit, and Schmitz 1980; Rogerson 1980). Even with these clear conceptual problems, expected Marshallian consumer's surplus is still widely used (e.g., Burt, Koo, and Dudley 1980; Taylor and Talpaz 1979).

Several authors have proposed measures to correctly determine consumer benefits in a stochastic setting. In particular, Anderson (1979a) and Helms

(1985) have argued that _ex ante_ compensating and equivalent variations are improved measures of consumer benefits when price is a random variable. These _ex ante_ measures are appropriate for evaluating climate information. The relevant compensation experiment is to determine how much income the potential user would be willing to forego in exchange for the information service before the outcome is known.

The expectations of Marshallian consumer's surplus measures typically applied in value-of-information studies (i.e., Bradford and Kelegian 1977) are _ex post_ and flawed if the problem is in fact _ex ante_. For instance, expected compensating variation is the amount of money income necessary, on average, to compensate a consumer for facing prices in a no-information regime if the compensation is paid _after_ the random price is observed. Clearly, this measure does reflet the willingness of the individual to pay for an information service before observing the actual price outcome.

Although _ex ante_ compensating and equivalent variations are appropriate welfare measures in a stochastic price setting, these measures have limited practical value. They require information about the risk attitudes of consumers and about the ordinal properties of the direct utility function. Alternatively, Hausman (1981) has shown that compensating and equivalent variation measures--and consequently the expected values of these measures--can be recovered from many common forms of estimable demand functions (e.g., linear, double log, etc.). These features of expected consumer's surplus measures may explain their continued use in empirical valuation studies. Choi and Johnson (1986) have provided further justification for the use of expected equivalent variation in empirical applications. They show that expected equivalent variation and _ex ante_ equivalent variation are identical if the individual is risk neutral. More importantly, they demonstrate that expected equivalent variation provides a lower bound for ex ante equivalent variation when individuals are risk averse in income. These favorable aspects of expected equivalent variation suggest it will be more widely applied in future studies of information value.

Impact Assessment Studies

The complexity of the valuation problem for climate infromation has led to a nubmer of exploratory or more descriptive research efforts. In general, the goal of thse descriptive studies is to determine the impact of a cliamte related event for a particular segment of the economy or society. For simplicity this broad category of descriptive studies have been labeled impact assessments. An example of an impact assessment is provided by an exercise conducted by Womack, Young, and Johnson (1985). They assessed the effect of the 1983 drought on the U.S. farm economy and concluded it caused a 24 percent decline in net farm income in 1983 relative to "normal" weather conditions. Another group of studies included as impact assessments are those attempting to infer causality between climate or weather related events and social or economic indicators such as prices, retail sales, unemployment rates, etc. An illustrative example of this kind of study is by Roll (1984) who examines the causal relationships between temperature and rainfall near Orlando, Florida and the prices of frozen concentrated orange joice futures contracts. Other studies have investigated causality between climate and socioeconomic indicators using modern time series methods (Fomby et al. 1984).

These descriptive impact assessment studies have a number of limitations if used as a basis for valuing weather forecasts. For instance, knowing that last year's drought cost U.S. farmers $6 billion in foregone income does not provide conclusive evidence about the value of long- or short-term weather forecasts for agriculture. Nor does this type of result help decision makers allocate resources to weather forecasting. Of course, part of the problem with the use of these descriptive studies in public or private decision making is identifying the beneficiaries of climate information. For instance, not only farmers benefit from a long-term weather forecast. Input suppliers, marketing firms, consumers, and even government agencies, to name but a few, might all be concerned about the prospects for favorable growing conditions. More importantly, these studies are, without exception, ex post.

Even though descriptive studies may be of little use in establishing a value of the system for sensing, recording, and disseminating climate information, they are not without merit. In fact, most of these studies are not so naive as to claim to establish a value of climate information or for the system generating the information. Although they are sometimes used as indicators of the dimensions of costs and benefits involved in climate forecasting for public policy, the principle worth of impact assessment studies is descriptive.

In a descriptive sense, impact assessments are useful in developing estimates of the potential uses of climate information and for isolating the effects of climate conditions on observed socioeconomic behaviors. In the latter case, by observing how and when climate information is being used, or how this information impacts the process of interest, improvements in the delivery system for climate information can be made. An improved understanding of the linkages between the climate and economic or social phenomena can also result in the design of a better framework for estimating the value of climate information. Thus, results of impact assessment studies are perhaps best viewed as intermediate products in the valuation process.

Review of Selected Studies

In recent years a number of studies have attempted to value climate information and/or particular weather information systems. The studies examining these and related issues are numerous and space prohibits a complete enumeration. Maunder (1970) and McQuigg (1975) provide more detailed surveys of climate impact assessments and climate forecast valuation studies. Our objective is to briefly highlight selected studies illustrative of the kinds of issues examined and the methods used to value climate information. In addition, emphasis is placed on the studies which have provided actual value estimates of improved climate information. As already indicated, the literature on the value of climate information generally falls into three broad categories:

1) the value of climatic information to individual decision makers,
2) the value of climate information at the market level, and
3) the identification of possible causal relationships between climatic impact variables (rain, wind, temperature, etc.) and various economic performance measures (prices, sales, etc.).

Individual Decision Applications

Of the three areas, primary research emphasis has been placed on valuing climate information at the individual decision-making level. Individual valuation studies are, as previously mentioned, generally couched in a decision theory framework. The individual is assumed to play a game against nature and to have probabilistic information about the possible outcomes. The game theory or "cost-loss ratio situation" approach generally assumes that decision makers must choose one of two actions: protect an activity or operation at a known cost or face the risk of, perhaps catastrophic, loss.

The Bayesian approach assumes the decision maker has knowledge about the conditional distribution of the forecast(s) relative to each state of nature (Anderson et al. 1977). The initial probabilities for each state of nature can then be revised in accordance with Bayes' Theorem. In all cases the decision maker is assumed to choose the action maximizing expected returns (minimizing expected costs) or maximizing expected utility.

Table 1 summarizes a number of applied studies which have examined the value of climate information for individual decision-making units. Studies which have used a Bayesian framework for analyzing the value of climate information include those by Baquet, Halter, and Conklin (1976); Katz, Murphy, and Winkler (1982); Stewart, Katz, and Murphy (1985); Hashemi and Decker (1968); and Byerlee and Anderson (1968). Anderson (1979b) and Lave (1963) have specifically used a "cost-loss" or game theoretic approach in valuing climate information. Additional studies have determined the value of weather information to individual decision-making units by using less structured subjective measures. These studies typically involve surveys of users in which the respondents are asked to place a subjective value on an information service. An example is the survey by Ewalt, Wiersma, and Miller (1973).

Market Applications

While studies investigating information value to individuals are numerous, far fewer inquiries of the social value of climate information have been made. Most of the studies assessing the social value of information use ex post Marshallian surplus or benefits measures. It is assumed that producers and/or consumers make economic decisions with uncertainty about the possible outcomes. The benefits of information result either because markets

Table 1. Summary of selected value of information studies.

Investigators	Subject	Climate Characteristics	Climate Impact Variables	Information Concept	Value System	Valuation Method	Conclusion
Baquet, Halter, and Conklin (1976)	Value of frost forecasts to pear orchard managers	Temperature	Bud damage and yield loss	Daily minimum temperature forecasts, historical weather information	Individual	Bayesian, expected utility maximization	U.S. Weather Service frost forecasts had approximate value of $5.39 per acre per day for risk averse decision makers.
Katz, Murphy, and Winkler (1982)	Value of frost forecasts to orchardists in Yakima Valley, Washington	Temperature	Bud damage and and yield loss	Daily minimum temperature forecasts, historical weather information	Individual	Bayesian, expected cost minimization, Markovian decision process	Value ranged from $809 to $270 per acre over the entire frost protection season.
Stewart, Katz, and Murphy (1984)	Value of frost forecasts to apple orchardists in Yakima Valley, Washington	Temperature, Dew Point	Bud damage and yield loss	Daily minimum temp. forecasts and post forecast temp. & dew point	Individual	Bayesian, expected cost minimization	Approx. $763 per acre for the entire frost protection season.
Wilks and Murphy (1985)	Value of precipitation forecasts for haying/pasturing decisions in western Oregon.	Precipitation, Temperature	Net income from pasturing or haymaking. Hay quality.	Seasonal precipitation forecasts	Individual	Bayesian, expected utility maximization	Value of current forecast ranges from $0-$.57 per acre, per day.
Hashemi and Decker (1968)	Irrigation scheduling in corn production	Precipitation	Irrigation frequency	Precipitation probability forecasts	Individual	Bayesian	Reduction in magnitude and frequency of supplemental irrigation. No monetary values were reported.
Ewalt, Wiersma, and Miller (1973)	Value of precipitation and field condition forecasts to Indiana farmers	Precipitation, Field Conditions	None	Precipitation and field condition forecasts	Individual	Survey (subjective)	Value of forecasts positively related to soil types. Highest values were obtained for spring months. No monetary values were attached.

Table 1. (Continued)

Investigators	Subject	Climate Characteristics	Climate Impact Variables	Information Concept	Value System	Valuation Method	Conclusion
Lave (1963)	Value of better weather information to the raisin industry	Precipitation, Degree Days	Grape yields and uses (i.e., raisins, crushing,etc.)	Perfect precipitation forecasts	Individual, Market	Game theory and impact on industry profits	The value of perfect three-week forecasts is $90.95 per acre. Partial equilibrium analysis shows that industry profits fall with improved weather forecasts.
McQuigg and Thompson (1966)	Natural gas demand in Columbia, Missouri	Heating Degree Days	Demand for natural gas	Forecasts of heating degree days	Individual	Loss function	Value of climate information depends on ability of user to effectively translate such information into economic terms.
Tice and Clouser (1982)	Value of weather information to individual corn producers	Minimum and maximum soil and air temperatures and daily rainfall	Corn and soybean yields	Probabilistic knowledge of weather indices	Individual	Accounting, expected profit maximization	By utilizing current weather information and probabilities of future weather events, result in increased returns of $1.48 to 3.99 per acre.
Anderson (1979)	Value of extended-period weather forecasts in pea production and logging	Temperature, Precipitation	Ripening date for peas. Road improvement costs for logging.	Probabilistic knowledge of weather data	Individual	Game theory (cost-loss)	Savings levels vary depending on the conditional probability of a "bad" outcome given that an unfavorable outcome has been predicted.
Mason (1966)	Value of meteorology to the United Kingdom economy	Various	Time lost in the building industry, reserve capacity of electricity, etc.	General weather forecasts	Market	Benefit-Cost ratios	Benefit-cost ratios of meteorological forecasts to many industries exceeds 15 to 1.

Table 1. (Continued)

Investigators	Subject	Climate Characteristics	Climate Impact Variables	Information Concept	Value System	Valuation Method	Conclusion
Maunder (1968)	An econoclimatic model for Canada	Rainfall, Mean Temperature and Sunshine	Canadian monthly retail sales	Climatic index weighted by population	Market	Accounting (Causal)	A one standard deviation in temperature below the mean could result in a $1.7 million increase in home heating oil sales. Similar results were obtained for other items.
Byerlee and Anderson (1969)	Value of rainfall predictors in wheat yield response functions	Rainfall	Wheat yield through nitrogen, rainfall, soil moisture interactions	Prediction of annual rainfall trends	Individual (ex ante)	Bayesian, expected profit maximization	Values of rainfall predictors ranged from 0.3-36.0 cents per acre.
Freebarin (1976)	Value of commodity price outlook information	-	Supply response is a function of producer price forecasts in previous periods	Improvement in the accuracy of commodity price forecasts	Market	Marshallian Surplus	Potential gross benefits for wool, lamb, wheat, barley, and potatoe markets in Australia was at least 1% of the gross value of the commodity.
Antonovitz and Roe (1984)	Value of rational expectations forecasts in the fed beef market	-	Supply response is a function of the expected mean and variance of price	Forecasts of the mean and variance of market price	Market	Marshallian Surplus	The average ex ante value of the rational expectations forecasts versus ARIMA forecasts was $.21 per cwt. over the 1970-80 period in 1972 dollars.
Womack, Young, and Johnson (1985)	Effect of abnormal weather on the U.S. agricultural economy over the 1983-86 period	-	Yields of major U.S. feed and food grains	Departure of yields from trend	Market	Impact Assessment	Model solutions were calculated for crop and livestock markets assuming normal (trend) and actual yields. The departure from trend in 1983 significantly altered prices, production, carry over, consumption, etc.

Table 1. (Continued)

Investigators	Subject	Climate Characteristics	Climate Impact Variables	Information Concept	Value System	Valuation Method	Conclusion
Bradford and Kelajian (1978)	The value of wheat crop forecast information in the U.S.	-	Wheat inventory adjustments	Wheat crop forecasts	Market	Marshallian surplus	Point estimate of the annual loss to the U.S. economy of less than perfect wheat crop forecasts is $64 million (1975 dollars).
Hayami and Peterson (1972)	The marginal social returns to improved crop and livestock statistics	-	Production and inventory adjustments	Reduced sampling error contained in USDA survey	Market	Marshallian Surplus	Marginal benefit-cost ratios associated with a 0.5 percent reduction in sampling error were found to be between 600 to 9 and 100 to 9.
Maunder (1966)	Climatic variations and agricultural production in New Zealand	Rainfall, Temperature, and Sunshine	Butterfat production, wool per acre, crop and fruit yields	Climatic variation indices	Individual Aggregates	Accounting (Causal)	A standard derivation departure from monthly average rainfall, temperature, etc. on butterfat production resulted in returns of ± $2.2 to ± $5.6 per cow. Similar results were obtained for other products.
Roll (1984)	The effects of weather information on near-term orange juice futures prices	Temperature, Precipitation	Level and variability in orange juice prices	Temperature and rainfall forecast errors	Market	Informational processing ability	Prices were significantly impacted by temperature forecast errors. Weather explains only a small portion of total price variability.

have a temporal dimension (i.e., inventory levels are adjusted) or because economic agents have the flexibility to adjust to new (better) information.

Figure 2 illustrates how the Marshallian framework is typically applied to estimate the social returns from improved climate information when markets are temporally linked. Arbitragers must decide the level of inventories to carry forward from period one on the basis of expectations about production in the second period. If it were known that quantity Q_1 would be produced in the first period and quantity Q_2 in the second period, then social value would be maximized by choosing an inventory level equating prices in the two periods (in the absence of storage costs and time preference for money). That is, the optimal inventory would divide total output $(Q_1 + Q_2)$ equally between the two periods. Now, suppose agents do not know Q_2--perhaps due to stochastic climatic onditions--and instead must use $Q_{2,1}$, which differs from Q_2 by a forecast error ε_2. Arbitragers will then hold in inventory an amount equal to $(Q_1 - Q_{2,1} - \varepsilon_2)/2$, which is $\varepsilon_2/2$ less than the amount $(Q_1 - Q_2)/2$. That is, if ε_2 is positive, too little inventory is held.

The dollar loss in consumption in period 2 is given by the hatched trapezoid in Figure 2b. This area shows the extra consumption value of perfect foresight. Period 1 consumption is correspondingly larger than it otherwise would have been, with the resulting dollar gain due to the additional consumption equal to the hatched area in Figure 2a. Since demand is nonrandom, the net loss in value relative to what would have occurred with a perfect forecast is given by the area of the rectangle with base ε_2 and height $\beta\varepsilon_2/2$ where $-\beta$ is the slope of the (linear) inverse demand function. Thus, the net social loss is $\beta\varepsilon_2^2/4$. An analogous argument holds when ε_2 is negative. Assuming that $E(\varepsilon_2) = 0$, the expected value of the social loss is given by $\beta\sigma^2/4$ where σ^2 represents the forecast error variance.

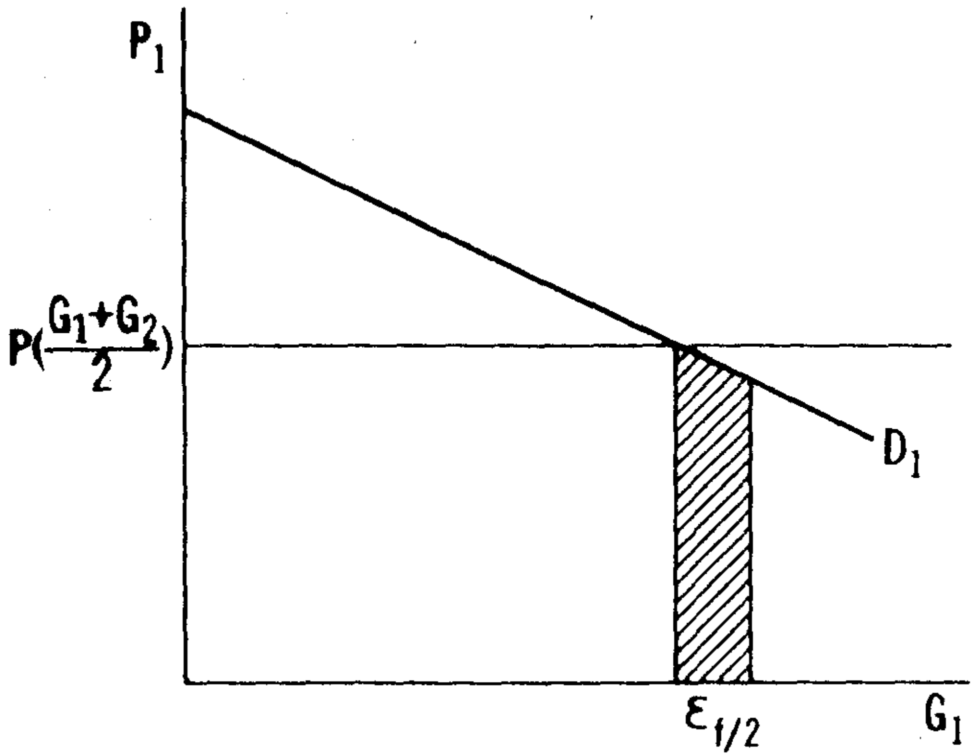

Figure 2a. Welfare Effect in Period 1.

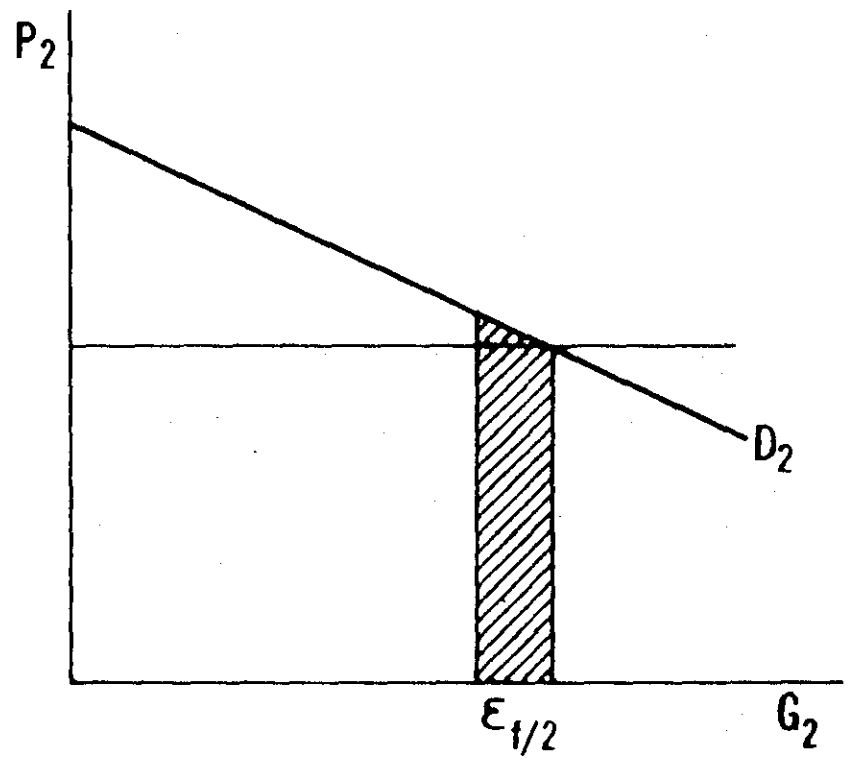

Figure 2b. Welfare Effect in Period 2.

Increasing the accuracy of the forecast (i.e., reducing the forecast error variance) can be evaluated to determine the marginal social benefit of improvements in forecasting accuracy. A similar framework can be used to evaluate the social benefit of improved intraseasonal forecasts when producers have the flexibility to adjust production responses to the new information. Various forms of the above approach have been used to value information for crop and livestock forecasting systems, e.g., Hayami and Peterson (1972), Bradford and Kelejian (1977, 1978), and Freebairn (1976). (See Table 1).

Only a few studies have attempted to directly estimate the social value of climate forecasting. The studies by Mason (1966) and Maunder (1966) fall into this category, although Maunder did not attach a numerical value to the climate information. In addition, the only study conducted in a rational expectations framework is by Antonovitz and Roe (1984), although their analysis did not focus on public policy. Lave (1963) also examined the potential worth of improved forecasts for the raisin industry. His conclusion was limited to the argument that better forecasts would result in larger output and, because of the inelastic nature of raisin demand, prices and revenues would fall. He did not estimate consumer benefit. Mason used intuitive estimates of benefit-cost ratios to analyze the social value of climate information in England. Clearly, considerable room exists for improving the estimates of the social worth of climate information. In addition to the theoretical problems identified in the previous section, market valuation studies have also been hampered by the fact that climate information is a publically available good and that a diversity of groups use climate information. This means that it is frequently difficult to account for all of the benefits which result from even a single climate related prediction.

Assessment

The final category of applied research concerns possible causal relationships or linkages between weather and observed market or social phenomenon. Examples are the studies by Maunder (1968); Roll (1984), and Womack, Young, and Johnson (1985) in Table 1. These studies do not estimate the value of climate information but instead investigate how markets respond to information about changing climatic conditions. Maunder found that retail sales of various consumer goods in Canada were significantly related to the level of precipitation, mean temperature, and sunshine. Roll concluded that nearby orange juice futures prices were significantly affected by temperature conditions near Orlando, Florida, although temperature seemed to explain little of the total volatility in price movements. Womack, Young, and Johnson studied several weather scenarios on the U.S. crop and livestock economies. The shocks caused by the 1983 drought were substantial and in many instances several years passed before the resulting disruptions to the time paths of endogenous variables appeared. These assessment studies are valuable for their descriptive content and they may be helpful to decision makers, but again they are only useful to the extent that adjustments can be made to changing weather information.

Valuation Puzzles

The review of selected empirical value-of-climate information studies and the brief sketch of the theory have suggested a number of problems or puzzles. If resolved, these valuation problems or puzzles represent opportunities for improving the scientific basis for designing climate information systems. The discussion of these puzzles or issues is not intended to imply that the process of providing a more systematic basis for valuing weather information is beyond reach, but instead that there is a broad opportunity for improvement. Of course, in any decision context (and if there is anything to be learned from the information and decision theory) the objective is to proceed with the best available data and theoretical concepts. Never will both be perfect. Changes in the perceptions of the valuation problem, the institutional setting, the available technology, and many other critical factors will keep valuation analysis in a constant state of flux.

Measures of Information

From the survey of applied valuation exercises, it is apparent that climatic information is rarely used in the form observed or reported. That is, the climate data as observed, recorded, and reported have time and space dimensions. Frequently, transfer functions are applied to these time and space dimensioned data to process them into a form consistent with individual information requirements. Examples include crop yield models, wind chill indices, short-term and long-term forecasts, degree days, soil moisture and temperature, etc. In assigning a value to climatic information it is important to recognize that there can be a confounding of the "information" implicit in the transfer functions with the observed or partially processed climate data provided by the system under study. That is, the value of climate information includes the value of the raw observations as well as the value of the information that underlies processors used to transform the data into a usable form. It may, in fact, be impossible to disentangle the value of the original or unrefined information from the transformation processes.

Who should assume responsibility for the development of these transfer functions and how are the priorities for developing these functions to be determined? Relatedly, are the transfer functions necessary because the system has been designed for purposes other than those of the present users? These and other questions are important for valuing climate information and for developing an appropriate scope for both public and private weather information services.

Presently, it appears that the U.S. climate information system follows a middle of the road approach in regard to these questions. That is, some processing of information and developmental work on transfer functions aimed at particular clients is accepted as the responsibility of the public agency. Alternatively, there are a number of individuals, organization, and firms privately processing the data provided by public information agencies to make it more useful in specific decision contexts. Of course, public organizations, including state-supported universities, also play a role in processing climatic information for specific public uses. Clearly, decisions about public and private responsibility for transfer function development and primary data collection will continue to have an important effect on assessments of the value of climate information, as well as on the design of the national climate information system.

Ex Ante Versus Ex Post Valuations

It is necessary to determine prior to the investment in an information system, whether the benefit will be greater than the cost. The readily available data on individual and market response to climate information, however, are largely *ex post*. Applying the appropriate (*ex ante*) valuation theory will be difficult at best since the majority of applied valuation studies rely on passively generated data (i.e., data not obtained in an experimentally controlled environment). Common forms of surplus measures (Hayami and Peterson 1972; Bradford and Kelejian 1978) ignore the obvious problems associated with using ex post secondary data to infer value. It is well understood that actions ranked on the basis of ex post measures of consumer and producer surplus cannot be similarly ranked by applying the same measures ex ante (Anderson 1979a, Helms 1985). These observations on valuation at the market level render most of the existing empirical results questionable.

The implications of this ex post versus ex ante conflict are, however, not all negative. Instead, the concepts suggest more constructive ways of proceeding with applied research in the valuation problem. Subjective probabilities should be elicited from potential users. A new set of subjective probabilities should then be elicited, after the respondents have altered their initial beliefs on the basis of new or additional information. If the message to be received is uncertain, then probabilities associated with possible messages should be estimated as well. In short, problems with ex ante valuation simply suggest the use of different types of data and different modeling approaches. These data, in general, cannot be obtained from secondary sources. The investigations using passively generated data are inexpensive but, as is becoming increasingly apparent, provide valuation estimates that are flawed.

Utility and Expected Utility Maximization

Most of the applied studies of the value of weather information in an individual decision context use Bayesian methods. These methods incorporate highly restrictive utility concepts. Only recently have utility functions which do not incorporate these very restrictive assumptions about attitudes toward uncertainty been applied in valuing climate information. Assuming that agents have concave utility functions, there is reason to believe that individuals are generally risk averse. The idea of risk aversion is critical to the value of information. It suggests, for example, that information which causes a decrease in the dispersion of the probability distribution on the states of the world has value. These benefits of information can not be reflected with linear utility functions, or expected profit functions, as implicit in many Bayesian applications.

A problem for applied work which attempts to accurately estimate the value of climate information is that if risk aversion is not incorporated, the information will be systematically undervalued. Clearly, much of the climatic information currently provided is intended to improve the reliability with which future climatic events--or the probable outcomes of physical processes that depend on climatic events--can be anticipated. If the effect of this information is simply to provide more reliable estimates of future events, then the major benefit of the information will be associated with reduced uncertainty. Thus, it is necessary to evaluate the implications of improved weather information for risk averse decision makers.

Short- and Long-Term Valuations

Much of the economic theory and applied work on information valuation have concentrated on short-term decisions. As is becoming increasingly apparent though, an important benefit of a climate information system is to provide a capacity for anticipating longer term events. In fact, some of the more successful applications of climate information in economic contexts have been associated with the prediction of events which have occurred over long time spans (Glantz 1977; Rassmussen 1986).

The long-term valuation of information is more difficult even within the present theoretical framework. Present versus future trade-offs of benefits and cost provide an unusually difficult problem when decisions are made under uncertainty. For instance, an important problem is to determine the appropriate social time discount factors. Whose time discount factors should be used; those of the present generation or future generations? Under what conditions is it possible to aggregate over individual decision-making units to obtain a social discount factor? These and other questions related to the methodology for valuing long-term climate information will lead to a new agenda of theoretical and applied research.

Distributional Effects

Decisions about the public production and dissemination of climate information frequently incorporate distributional concerns. For instance, individuals in agricultural markets serviced by weather information systems may benefit relative to other less informed participants. On what basis can society determine the relative utility of benefits generated by the supply of climate information among individuals, and groups of individuals? These are very complicated questions and ones that cannot be easily resolved within the current economic framework. It may, in fact, be that many of the individual benefits of information may wash from a societal standpoint. Having better informed groups of market participants, for example, may simply result in a redistribution of income, leaving total social well-being unaffected. The whole area of social welfare and distributional effects has been a prickly issue in economic thought for a long time. But for policy decisions, particularly in the design of public services, such problems cannot be dismissed without inviting future difficulties.

Public versus Private Information Systems

The design of the U.S. climate information system is the result of a number of deliberate decisions, natural crises, and other factors. Current and future discussions must be concerned with the appropriate division between private and public responsibility. These questions on public versus private responsibility are usually decided by economists on the basis of efficiency. That is, can the public agency provide the information more efficiently than individuals in the private sector? When does the market system fail, resulting in a welfare gain from public intervention? Having established the market, which, if any, components of the public sector's responsibility should be transferred to the private sector? Given the changing technology for sensing, recording, and distributing forecasts from the weather system, this issue will continue to evolve.

The difficulty in determining the appropriate division of private and public responsibility is also related to the transfer function question. All individuals who are users of climatic information must, in one fashion or another, specialize the information to their individual decision needs. These individuals may develop their own personalistic transfer functions or invest in transfer technology that can be shared. To what extent can this specialization be accommodated given the public-private split in responsibility for information services?

Impact Assessments

The descriptive work on impact assessments can be viewed from several standpoints. Unfortunately, it is not always clear which of these, if any, objectives have guided this research. One alternative is to provide descriptive information for developing appropriate transfer functions or improving the design of valuation problems. Of course, these conclusions are dependent upon the current design of the system. From the results of impact assessments involving causal linkages between climate and other observed phenomena, it is possible that researchers can improve the framework for studying information system design and valuation problems. It is emphasized, however, that since these results are conditioned on the current information system, they are likely to simply reinforce the status quo.

A second way to view these descriptive studies is as a means of short-cutting many of the complexities of the formal valuation problem. Simply put, the intent is to show the association of information on climate with observed economic or social activity. Since these assessments essentially represent reduced forms of highly complex systems, care should be taken in attaching causality. It is likely that the linkages between market-determined outcomes and weather data are a result of a system of transfer functions and social and individual values. Thus, these impact assessment studies should be viewed as simply indicating gross associations between market or social activities and climate-related information.

Concluding Observations

Our objective has been to provide an assessment of the results on the valuation of climate information and the methods currently used for developing these valuation measures. A major conclusion in both instances is that the refinements and extensions in decision theory present an opportunity for making important advances in the valuation problem. These advances may lead to workable structures and methods for developing measures of value from a market or societal perspective. From an economic standpoint, these valuation measures require assumptions that are only beginning to be fully understood.

A flurry of activity in the market valuation area is likely as the uncertainty and rational expectations theories are merged in information valuation studies.

A second conclusion concerns the measure of information and, perhaps more importantly, the way data from the climate information system find their way into use in economic and social activities. Much of the work on the value of climate information is implicitly related to the value of this information as an input into transfer functions -- functions which include extensive types of prior and empirical information not related to weather, e.g., plant simulation models. Thus, if we are to provide an improved basis for valuing the system, the role of these transfer functions and their implicit information content must be more clearly recognized and incorporated. The explicit introduction of transfer functions into valuation analysis becomes especially difficult when private versus public generation and delivery systems are contemplated.

A final note is in order, albeit brief, about impact assessments. This is a valuable activity if it is properly recognized as descriptive. More descriptive information must be accumulated to assist in identifying causal linkages. However, assessments must be regarded carefully in valuation contexts since they invariably support the existing information system design. That is, impacts are conditioned by the information supplied. To use these valuation results to design the production and delivery system for climate information is circular. These impact assessments are especially troublesome problems in an era of rapidly changing technologies when simple measures of performance are desirable. The valuation problem is difficult. But the costs of not addressing it directly can be high, both for economists, who must ultimately advance the theory of information, and for those directly involved in planning and designing current and future climate information systems.

Reference List

Anderson, J.E. "On the Measurement of Welfare Costs under Uncertainty." Southern Economic Journal 45(1979a):1160-71

Anderson, L.G. "The Economics of Extended-Term Weather Forecasting." Monthly Weather Review 101(1979b):115-125.

Anderson, J.R., J.L. Dillon and B. Hardaker. Agricultural Decision Analysis. Ames: Iowa State University Press, 1977.

Antonovitz, F., and T. Roe. "The Value of a Rational Expectations Forecast in a Risky Market: A Theoretical and Empirical Approach." American Journal of Agricultural Economics 66(1984):717-23.

Arrow, Kenneth J. "Aspects of the Theory of Risk-Bearing." Helsinki: Yrjo Jahnssonin Saatio, 1965.

Baquet, A.E., A.N. Halter, and F.S. Conklin. "The Value of Frost Forecasting: a Bayesian Appraisal." American Journal of Agricultural Economics 58(1976):511-20.

Baron, D. "Price Uncertainty, Utility, and Industry Equilibrim in Pure Competition." International Economic Review 11(1970):463-80.

Bradford, D.F. and H.H. Kelejian. "The Value of Information for Crop Forecasting in a Market System: Some Theoretical Issues." Review of Economic Studies 44(1977):519-31.

_______. "The Value of Information for Crop Forecasting with Bayesian Speculators: Theory and Empirical Results." The Bell Journal of Economics 9(1978):123-44.

Burt, O.R., W.W. Koo, and N.J. Dudley. "Optimal Stochastic Control of U.S. Wheat Stocks and Exports." American Journal of Agricultural Economics 62(1980):172-87.

Byerlea, D.R., and J.R. Anderson. "Value of Predictors of Uncontrolled Factors in Response Functions." The Australian Journal of Agricultural Economics 13(1969):118-27.

Chavas, J.P., and S.R. Johnson. "Rational Expectations in Econometric Models." In New Directions in Econometric Modeling and Forecasting in U.S. Agriculture. Edited by C.R. Rausser. New York: Elsevier-North Holland, 1983.

Choi, K.E., and S.R. Johnson. "Consumer's Surplus and Price Uncertainty." Dept. of Economics Working Paper, Iowa State University, Ames, Iowa, 1985.

Choi, K.E., and S.R. Johnson. "Market Demand Uncertainty and Commodity Price Stabilization." Dept. of Economics Working Paper, Iowa State University, Ames, Iowa, 1986.

Ewalt, R.E., D. Wiersma, and W.L. Miller. "Operational Value of Weather Information in Relation to Soil Management." Agronomy Journal 65(1973):437-39.

Fama, E.F. "Efficient Capital Markets: A Review of Theory and Empirical Work." Journal of Finance 25(1970):383-417.

Freebairn, J.W. "The Value and Distribution of the Benefits of Commodity Price Outlook Information." The Economic Record 52(1976):199-212.

Fomby, T.B., R.C. Hill, and S.R. Johnson. Advanced Econometric Methods. New York: Springer-Verlag, 1984.

Glantz, M. "The Value of a Long-Range Weather Forecast for the West African Sahel." Bulletin of the American Meteorological Society 58(1977):150-158.

Gould, J.P. "Risk, Stochastic Preference, and the Value of Information." Journal of Economic Theory 8(1974):64-84.

Grossman, S.J., and J.E. Stiglitz. "Information and Competitive Price Systems." American Economic Review 66(1976):246-53.

Hausman, J.A. "Exact Consumer's Surplus and Deadweight Loss." American Economic Review 71(1981):662-76.

Helms, L.J. "Errors in Numerical Assessment of the Benefits of Price Stabilization." American Journal of Agricultural Economics 67(1985):93-100.

Hess, J. "Risk and the Gain from Information." Journal of Economic Theory 27(1982):231-38.

Hirshleifer, J. "The Private and Social Value of Information and the Reward to Incentive Activity." American Economic Review 61(1971):561-74.

Hirshleifer, J., and J. Riley. "The Analysis of Uncertainty and Information." Journal of Economic Literature 17(1979):1375-1421.

Hashemi, F., and W. Decker. "Using Climatic Information and Weather Forecast for Decisions in Economizing Irrigation Water." Agricultural Meteorology 6(1969):245-57.

Hayami, Y., and W. Peterson. "Social Returns to Public Information Services: Statistical Reporting of U.S. Farm Commodities." American Economic Review 62(1972):119-30.

Hayek, Friedrich A. "The Use of Knowledge in Society." American Economic Review 35(1945):519-30.

Katz, R.W., A.H. Murphy, and R.L. Winkler. "Assessing the Value of Frost Forecasts to Orchardists: A Dynamic Decision-Making Approach." Journal of Applied Meteorology 21(1982):518-31.

Kunkel, J.G. "Sufficient Conditions for Public Information to Have Social Value in a Production and Exchange Economy." Journal of Finance 37(1982):1005-13.

Lave, L.B. "The Value of Better Weather Information to the Raisin Industry." Econometrica 31(1963):151-64.

Leland, H.E. "The Theory of the Firm Facing Uncertain Demand." American Economic Review 62(1972):278-91.

Malinvaud, E. "A Planning Approach to the Public Good Problem." Swedish Journal of Economics 73(1971):96-112.

Maishak, J. "Economics of Information Systems." In Frontiers of Quantitative Economics. Edited by M.D. Intriligator. Amsterdam: North-Holland, 1971.

Mason, B.J. "The Role of Meteorology in the National Economy." Weather 21(1966):382-393.

Maunder, W.J. The Value of Weather. London: Methuen, 1970.

Maunder, W.J. "Climatic Variations and Agricultural Production in New Zealand." New Zealand Geographer 22(1966):55-69.

Maunder, W.J. "An Econoclimatic Model for Canada: Problems and Prospects." Paper presented at the Conference and Workshop on Applied Climatology of the American Meterological Society, Asheville, North Carolina, 1968.

McCall, John J. "The Economics of Information and Optimal Stopping Rules." Journal of Business 38(1965):300-17.

McQuigg, James D. Economic Impacts of Weather Variability. Atmospheric Science Department, University of Missouri, 1975.

McQuigg, J.D., and R.G. Thompson. "Economic Value of Improved Methods of Translating Weather Information into Operational Terms. Monthly Weather Review 94(1966):83-7.

Murphy, A.H., and B.G. Brown. "User Requirements for Very-Short-Range Weather Forecasts." In Nowcasting. Edited by K. A. Browning. London: Academic Press, 1982.

Muth, J.F. "Rational Expectations and the Theory of Price Movements." Econometrica 29(1961):315-35.

Newberry, D.M.G., and J.E. Stiglitz. The Theory of Commodity Price Stabilization. Oxford: Oxford University Press, 1981.

Pope, R.D., J.P. Chavas, and R.E. Just. "Economic Welfare Evaluation for Producers under Uncertainty." American Journal of Agricultural Economics 65(1983):98-107.

Pratt, John W. "Risk Aversion in the Small and in the Large." Econemetrica 32(1964):122-36.

Rasmusson, E.M. "Understanding and Predicting Year-to-Year Climate Variability." Paper presented at the Seminar on Policy Aspects of Climate Forecasting at the National Academy of Sciences, Washington, D.C., 1986.

Riley, J.G. "Informational Equilibrium." Econometrica 47(1979):331-59.

Rogerson, W.P. "Aggregate Expected Consumer Surplus as a Welfare Index with an Application to Price Stabilization." Econometrica 48(1980):423-36.

Roll, Richard. "Orange Juice and Weather." The American Economic Review 74(1984):861-80.

Rothschild, M., and J.E. Stiglitz. "Increasing Risk I: A Definition." Journal of Economic Theory 2(1970):225-43.

Sandmo, A. "On the Theory of the Competitive Firm under Price Uncertainty." American Economic Review 61(1971):65-73.

Stewart, R.T., R.W. Katz, and A.H. Murphy. "Value of Weather Information: A Descriptive Study of the Fruit-Frost Problem." Bulletin of the American Meteorological Society 65(1984):126-37.

Stigler, G.J. "The Economics of Information." Joural of Political Economy 69(1961):213-25.

Taylor, C.R., and H. Talpaz. "Approximately Optimal Carryover Levels for Wheat in the United States." American Journal of Agricultural Economics 61(1979):32-40.

Tice, T.F., and R.L. Clouser. "Determination of the Value of Weather Information to Individual Corn Producers." Journal of Applied Meteorology 21(1982):447-52.

Turnowsky, S.J., H. Shalit, and A. Schmitz. "Consumer's Surplus, Price Instability, and Consumer Welfare." Econometrica 48(1980):135-52.

von Neumann, John, and Oskar Morgenstern. Theory of Games and Economic Behavior. Princeton: Princeton University Press, 1944.

Waugh, F.V. "Does the Consumer Benefit from Price Instability?" Quarterly Journal of Economics 58(1944):602-14.

Womack, A.W., R. Young II, and S.R. Johnson. "Climate Impacts for the U.S. Agricultural Sector." Paper presented at the Conference for Climate-Economic Impact Assessments: Methods and Applications, Fredericksburg, Virginia, 1985.

Wilks, D.S., and A.H. Murphy. "On the Value of Seasonal Precipitation Forecasts in a Haying/Pasturing Problem in Western Oregon." Monthly Weather Review 113(1985):1738-45.

Wright, B.D. "The Effects of Ideal Production Stabilization: A Welfare Analysis Under Rational Behavior." Journal of Political Economy 87(1979):1011-33.