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ABSTRACT

This paper examines the complex nature of the process of economically valuing climate/weather forecasts. A discussion of both micro- (producer) and sector (market) economic issues is obtained through a review of previous studies. Integration of these issues is necessary to obtain the overall value of current or improved climate/weather forecasts. Previous studies have predominantly been concerned with valuing climate/weather forecasts at the producer level. By considering only producer level effects, the estimates of the value of climate/weather forecasts ignore market adjustments. Potential biases caused by ignoring these adjustments are illustrated.

INTRODUCTION

It is well known that weather and climatic conditions exert a strong influence on human activities. The major goal of various national and international climatic programs is to minimize the adverse and maximize the positive socioeconomic consequences of weather and climatic variations (Mason, 1978; Lamb, 1981; World Meteorological Organization, 1978). The capability to better predict weather and climate events is likely to be the skill which ultimately achieves these objectives. Using forecast information to improve societal well-being requires satisfying three demanding, reasonably sequential prerequisites. These are: 1) identification of the most severely impacted economic sectors, 2) determination of which of these sectors possess the flexibility to benefit from the use of climatic forecasts in decision making, and 3) the development of accordingly focused climate forecast schemes (Lamb, 1981).

Satisfying the third prerequisite requires that socioeconomic evaluations be performed to ensure that weather and climate forecast deliver economic value. A number of studies have assessed the value of either actual or potential forecast capabilities. One objective of this study is to review the findings of these studies relative to the general determinants of information value. In general, these studies have considered information value from the perspective of the individual (or firm level) decision maker. The paper's second objective is describe and contrast methodologies that are appropriate at the individual level (microeconomic level) with a conceptual framework appropriate for analysis at regional or national levels (sector level).

Microeconomic analysis is concerned with the effect that climate and weather information have on the decision making process for an individual manager. Usually it is assumed that the individual manager's decisions have little effect on the market price and supply of the relevant good. Sector analysis is concerned with the information's effect on the overall supply of that good and therefore its market price. This effect is the result of aggregate reaction of the individual firms to the climate information. By considering the aggregated effect, changes in the well being of both consumers and the producers can be estimated.

The subject matter of this study is restricted to that of valuation of weather and climate forecasts. A thorough discussion of methodologies for economic analysis of climate impacts is provided by Lovell and Smith (1985). Consideration of alternative approaches to the question of climate change is given in by Sonka and Lamb (1987). A comprehensive review of the methods appropriate for forecasting in general (not limited to meteorological events) is available in Armstrong (1985).

This review does not address the important topic of what meteorological research, process, or data gives rise to the forecasts. Rather this review determines what socioeconomic issues arise as a result of availability of either current or <u>ex-ante</u> weather and climate forecasts. Although the terms weather and climate have distinctly differing means in a physical sense, the socioeconomic issues associated with evaluation of these forecasts are quite similar. Therefore, the valuation of both types of events are considered here. (For brevity, "climate" will henceforth be used to refer to both climate and weather.) Further the question of which sector provides the forecast (private versus public meteorological service) is not addressed. The topics developed in the following sections apply to all weather and climate forecasts regardless of their source. Studies such as Roth (1963), Collins (1956), or Wallace (1971) suggest that private meteorological services' forecasts may be more valuable than National Weather Service's forecasts. They argue that private forecasts are provided in a more relevant form than public forecasts.

The remainder of the article is organized as follows. First estimates of value from past studies are presented and discussed. The factors evaluated in these and other studies are then considered in the context of the general determinants of information value. Next a methodology to evaluate forecast value at the individual or micro level is presented. This is followed by an analysis of the conceptual framework needed to perform evaluations at the sector level. A discussion of associated research implications concludes the.paper.

ESTIMATES OF THE VALUE OF WEATHER AND CLIMATE FORECASTS

Diverse economic activities such as construction (Prior and King, 1981; Russo, 1966; Greenburg, 1976), gas and electric utilities (Andrews, 1982; Suchman et al., 1979, 1981; Weiss, 1982), retail trade and business

(Maunder, 1973; Roth, 1963; Hallanger, 1963), aviation (World Meteorological Society, 1968), road and street departments (Suchman et al., 1979, 1981), and agriculture (Sonka et al., 1982, 1986, 1987; Mjelde et al., 1988; Brown et al., 1986; Vining et al., 1984; Winkler et al., 1983) have been shown to be affected by climatic or weather conditions. These studies suggest that decision makers can or do derive economic value from either actual or hypothetical climate forecasts. (A more complete bibliography is presented in Mjelde and Frerich, 1987).

A natural question is what are the magnitude of these benefits? Table 1 summarizes the economic benefits reported in a sample of previous studies relating to the value of climate information. (Throughout this review the value of forecasts as determined by previous studies will be presented in the units given by the original researchers.) The magnitude of the estimates indicate the different value alternative decision making processes place on climate forecasting. For example, Katz et al. (1982) report that current daily weather forecasts have realized approximately 66% of the potential of perfect forecasts in reducing frost protection costs in apple orchards. Caution is advised in using the values in Table 1 without first referring to detailed descriptions in the appropriate study.

The value estimates in Table 1 are not meant to be all-inclusive but rather are illustrative of a number of issues. First, there appears to be a consensus that climate forecasts do or would have value. Often that value is found to be relatively small for the individual decision maker but, because of a large number of decision makers or reference to a significant economic activity, the implied total benefits may be substantial. The preponderance of the studies, however, relate only to the individual or firm decision making level and do not quantify benefits at a more aggregate level. Second, the sector most often evaluated is that of production agriculture, presumably because of the climate sensitivity of that sector and the availability of data. Within the total agricultural sector, most of the value added created in the agricultural sector, however, occurs in non-farm firms (Tomek and Robinson, 1981). Therefore a significant gap in our understanding may exist relative to firms and industries where perfect competition is not the norm. Third, the attribute considered in prior studies is nearly always that of forecast accuracy. Yet, as detailed in the following section several other determinants of information value can markedly affect the usefulness of forecast information.

The preceding discussions, and the framework of this entire paper, focuses primarily on economic implications of forecast information use. For example, the values reported in previous studies do not include any valuation of scientific knowledge that could possibly be gained from forecasting climatic conditions. In developing climate forecasts, additional knowledge is likely to be generated which applies beyond climate forecasting.

MICRO LEVEL CONCEPTS

For climate information to possess economic value, decision strategies must be flexible in the sense that managerial actions can be altered in response to the information (Mjelde et al., 1988). Flexible decision strategies allow for continual reevaluation of management plans as the physical, economic and social environment in which they operate changes. Flexible decision environments are characterized by three elements. First, decision variable(s) must be able to take on alternative levels at the manager's discretion (Merkhofer, 1977). Second, an interaction between climatic conditions and the decision variable(s) must exist (Byerlee and Anderson, 1969). The nature of this interaction must, at a minimum, be partially understood by the decision maker. Finally, management must have the capability and willingness to adopt a flexible management strategy (Sonka, 1985). This final condition involves not only the two elements listed above, but the integration of climate forecasts into the decision process. For decision makers to incorporate climate forecast information into their decision making process, an information system must provide the forecasts in terms that are relevant to their particular decision making process. The following subsections discuss the characteristics which determine forecast relevancy. Note that various economic activities may place different value on the same forecast characteristic (Thompson, 1972; Suchman et al., 1979).

There are four general determinants of information value (Hilton, 1981). One of these refers to the characteristics of the information system itself. The other three are: 1) the structure of the decision set, 2) the structure of the decision environment, or equivalently the decision maker's current technology, environment,

Table 1. Economic Valuation of Climate/Weather Forecasts as Reported in Selected Studies[a]

Study	Economic Activity	Economic Value (Units)	Forecast Attribute[b]	Forecast Design[c]	Economic Unit
Brown et al. (1986)	Wheat Production	$ 10.08/ha/yr $196.62/ha/yr	Accuracy	Current, Perfect	Individual
Bergen and Murphy (1978)	Residential Housing and Wind Damage	$200,000/yr	Accuracy	Improved	Market
Byerlee and Anderson (1982)	Fodder	$312/farm/yr	Accuracy	Perfect	Individual
Greenberg (1976)	Agriculture Construction Boating Flood Control	$50-120 million/yr $50-130 million/yr $ 1 - 4 million/yr $ 4- 12 million/yr	Accuracy	Improved	Market
Hofing et al. (1987)	Seed Corn Production	2 to 5% of total production costs	Accuracy	Perfect	Individual
		1 to 3% of total production costs	Accuracy	50% Accurate	Individual
Katz et al. (1982)	Orchard	$270/ac/season $569/ac/season	Accuracy	Current, Perfect	Individual
Mjelde et al. (1988)	Corn Production	Results dependant on the attribute being valued.	Prior know-ledge, Ac-curacy , and1 lead time	Improved, Perfect	Individual
Mjelde and Cochran (1988)	Corn Production	$0.00-218/ha/yr	Prior Know-ledge, risk aversion	Perfect	Individual
Sonka et al. (1987)	Corn Production	$21.20-45.99/ha/yr	Accuracy, Periods of the year	Perfect, Improved	Individual
Thompson (1972)	All Processes Totalled	$739 million	Accuracy	Perfect	Market
Vining et al. (1984)	Agriculture	$1420/farm/yr	Accuracy	Perfect	Individual
Wilks and Murphy (1986)	Corn/Wheat Production	$.004-.138/ha/yr	Accuracy	Current	Individual

a) Inclusion of any study in this table is for illustrative purposes only, and not an endorsement by the authors. Readers should refer to the appropriate studies and consider their setting and limitations before using any of the values presented here. Values are given in the units presented by the studies' author(s)

b) Terms used to denote forecast attributes are: 1) Accuracy which refers to predictive accuracy of the forecasts, 2) prior knowledge which refers to the decision maker's initial knowledge on the probability of climate/weather events, 3) lead time refers to the time lag between the availability of the forecast and the period forecast, 4) risk aversion refers to the decision maker relative preferences for outcomes, and 5) periods of the year refers to forecasts for different times of the year.

c) Forecast design refers to the accuracy of the forecast. Studies denoted with current valued NWS forecasts as the forecast are presently given. Improved and perfect refer to increases in accuracy of the forecasts.

and relative preferences for outcomes, and 3) the decision maker's initial knowledge about the distribution of the stochastic variable(s) in the decision environment. Each of these four general determinants will now be discussed.

Climate Forecast Characteristics

The characteristics of any information system can be summarized around the concepts of timeliness, accuracy and relevancy. For climate forecasts a more specific characterization is (Sonka et al., 1986; Lamb, 1981; Mjelde, 1985):

1) Timing of the forecast availability (lead time), i.e. the time lag between availability of the forecast and the period being forecast,

2) Predictive accuracy (categorical versus probabilistic); if probabilistic, the conditional probability density function which describes the probability of the various climatic events occurring given the forecast,

3) The number of future periods forecast at a given point in time,

4) Spatial resolution, the potential divergence between regional climate forecasts and climatic outcomes for a specific smaller area within the region,

5) Time span of a given forecast (e.g., hour, day, week, month, season, year),

6) Specificity of the forecast, i.e. how many separate climatic categories are possible for a given period (e.g. three categories above average, average or below average versus five categories), and

7) The weather parameters (e.g., rainfall, temperature) to be forecast.

Of these design characteristics, accuracy has received the most attention in the literature (e.g., Byerlee and Anderson, 1969, 1982; Doll, 1971; Lave, 1963; Wilks and Murphy, 1985; Winkler et al., 1983; Baquet, et al., 1976; Dryer and Baier, 1981; Katz et al., 1982; Nelson and Winter, 1964). Studies have argued that the dissemination of probabilistic rather than of categorical forecasts increases the socioeconomic value of climate forecasts (Stuart, 1982; Murphy, 1977; Thompson, 1962; Price, 1949). Accuracy has received the most attention because conceptually it is easier to understand how this characteristic affects the value of climate forecasts.

Forecast accuracy, however, is not itself a simple parameter to describe. Quantitative measures of accuracy or information content, such as entropy (Mjelde et al., 1988), probability score (Murphy and Thompson, 1977), and variance of the forecast (Brown et al., 1986), have been used in previous studies. Work by Katz et al. (1987), Murphy and Thompson (1977), and Peel et al. (1988) suggest that it is unlikely that any empirical measure of forecast accuracy will have a monotonic relationship with the economic value of the forecast. Further the analysis by Peel et al. (1988) indicates that knowing how often a forecast is correct is not sufficient to determine economic value. The manner in which a forecast scheme is incorrect can be as important in determining economic value.

Easterling (1986), in surveying paying subscribers to NOAA's Monthly and Seasonal Weather Outlook, found that the most important factor in discriminating between systematic users and nonusers of climate forecasts is not accuracy but rather is the lack of lead time associated with the forecast. Mjelde et al. (1986) and Mjelde and Dixon (1989) provide different methodological approaches to ascertain the value of lead time. These studies, along with Easterling and Mjelde (1987), suggest that there is a possible trade-off between accuracy and lead time in dynamic production settings. In some cases **a** less accurate forecast known earlier in the production process can have a higher value than a more accurate forecast provided at a later date. Other studies which indicate the importance of lead time in climate forecasting, are Sonka et al. (1987), Vining et al. (1984), Stuart (1982), and Weiss (1982).

Mjelde el al. (1988) suggest that there are possible synergistic effects of knowing the climate forecast for adjacent time periods within a dynamic production process. For example, the value of forecasting early and midsummer (June and mid July) jointly is worth $1.43/acre/year more than the sum of individually forecasting each time period for Illinois corn production. Mazzocco extends this analysis to include two crops, soybeans and corn for Illinois and Iowa. Thompson (1972) indicates the length of the forecast period is dependent upon the decision making process. For example, aviation might be concerned with wind and precipitation on an hourly basis, while crop production processes are more concerned with precipitation levels throughout the growing season.

Two design characteristics that have received little prior research attention are spatial resolution and specificity. Spatial resolution can be thought of as a specific type of forecast accuracy. That is, if the spatial resolution of a specific forecast is broad relative to the decision making area of interest, the forecast can be viewed as being relatively less accurate for the manager. In assessing the value of forecasting five versus three climate condition categories, Mjelde (1985) concludes that the economic conditions may be more important than the specificity of the forecast.

Rench and Makosky (1978) suggest changing the parameters included in agricultural weather forecast programs for Arkansas agriculture would increase the economic value of these programs. Specifically they suggest that average maximum daily rainfall, average daily rainfall, dew formation, and dew point temperatures be removed from the weather programs. In their place, they suggest adding the time of day relative humidity will drop below or rise above 60 percent, wind forecast, and the timing of the occurrence of 90° and 32° temperatures if applicable for any one day. Wilks and Murphy (1986) determined the economic value of bivariate seasonal forecasts (precipitation and temperature) of the form currently issued by the U.S. National Weather Service. Their results indicate that the current forecasts may have considerable value across the northwestern margin of the corn belt. Nelson and Winter (1964) examine what they refer to as the "minimum message sufficient information system" in terms of the minimum number of weather parameters necessary in a forecast. The preceding results suggest that the design characteristics are important and the individual decision making process determines the economic value placed on each characteristic.

Methodology to Value Climate Forecasts

Several methodological procedures based on decision theory have been utilized to value climate information. These include cost/loss (Gleeson, 1960; Murphy, 1976; Stuart, 1982; Thompson, 1972; Gandin et al., 1980; Murphy et al., 1985), willingness-to-pay (Vining et al., 1984), minimax strategy (Gleeson, 1960) and maximization of expected net returns (Doll, 1971; Byerlee and Anderson, 1969, 1982). As the review of literature illustrates, prior studies have tended not to consider the full range of information determinants that can affect forecast value. Instead there has been a preoccupation with assessing the effect of accuracy only. Significantly less attention has been devoted to theoretically important attributes such as lead lime, alternative weather parameters, composition of the forecast period, and forecast specificity.

Whatever forecast parameters are of interest, the appropriate methodological approach is determined by the decision maker's objective(s) (Hallanger, 1963; and Gleeson, 1960). Because maximization of expected net returns has been a widely used objective function in previous studies, it is developed in some detail here. Only slight modifications of this framework are necessary to evaluate the different determinants of information value. Furthermore, the framework is sufficiently robust to accommodate different decision maker's objectives with only slight modifications.

In this framework, let e represent the stochastic climatic variable and X be the variable under the control of the decision maker. Furthermore, assume an interaction exists between e and X which is understood by the decision maker. The decision maker's problem is to maximize expected net returns, U(e,X), in the absence of any information other than the decision maker's prior knowledge of the probabilities of e, p(e),

$$\max_{X} \int U(eX)\, p(e)\, de. \tag{1}$$

The value of X which maximizes (1) is represented by X*. Suppose the decision maker obtains a particular climate forecast, P_k which modifies p(e) to give p(e|Pk). Assuming the forecast is reliable, the decision making problem is now,

$$\max_{X} \int U(e,X)\ p(e|P_k)\ de. \tag{2}$$

Let X_k be the value of X which maximizes (2). The value of forecast P_k is given by

$$\max_{X} \int U(e,X)\ p(e|P_k)\ de - \int U(e,X^*)\ p(e|P_k)\ de. \tag{3}$$

The gain in expected net returns is the difference between the expected net returns when using the forecast optimally and the expected net returns derived from the decision maker's prior knowledge (X*) when the actual climatic conditions occurring are those forecasted by P_k.

Forecast P_k is only one possible prediction that could be generated by the forecast information system. The expected value of a forecasting system which generates forecasts P_k with probability distribution p(k) is

$$V = \int \max_{X} \int U(e,X)\ p(e|P_k)\ de\ p(k)\ dk -$$

$$\int\int U(e,X^*)\ p(e|P_k)\ de\ p(k)\ dk. \tag{4}$$

The gain from the forecasting system is the difference between the expected net returns when the forecasts are used optimally and the expected net returns when the action is selected without utilizing the additional information. Note that if X_k = X* for all k, the information system has no value because no decisions are changed.

In the context of agricultural production the use of equations (1) through (4) can be illustrated through the following simplified example. Assume a farmer plants corn and the only input that can be varied is the amount of applied nitrogen. The farmer, in the absence of the climate forecast, uses (1) to determine how much nitrogen to apply. Let this amount equal 100 kg/ha. Suppose a perfect climate forecast becomes available, and the forecast is for above average rainfall. The farmer would incorporate this into the decision making process by the use of (2). Let the optimal nitrogen amount associated with above average rainfall be 150 kg/ha. The expected net returns using 100 kg/ha and then using 150 kg/ha of applied nitrogen for above average rainfall amounts must be determined in order to place a value on the forecast. Let the expected net returns associated with above average rainfall be $100/ha if 100 kg/ha of nitrogen was applied and be $120/ha if 150 kg/ha were applied. The value of the forecast obtained from (3) would be $20/ha. The expected net returns attributed to applying 100 kg/ha of nitrogen cannot be attributed to the value of the forecast. The farmer would have received these net returns if no forecast was received. Therefore, the value of the forecast is the increase in expected net returns attributed to the forecast. Above average rainfall is only one possible forecast (two other obvious forecasts are average and below average rainfall). The total value of the forecasting system is obtained using (4).

The preceding discussion assumed that the decision maker was concerned only with average profits over time. However, decision makers are believed to be concerned with year-to-year variability of returns (risk) as well. Therefore, decision maker's risk attitude is likely to affect the economic value placed on climate forecasts (Baquet et al., 1976; Byerlee and Anderson, 1982). Byerlee and Anderson (1982) show that there is not necessarily a positive correlation between risk aversion and the value of information. In addition to the risk associated with the stochastic event, they indicate two further sources of risks associated with obtaining additional information. First, unless the forecast is perfect there is still a measure of risk associated with the climatic conditions that will occur. By definition, however, this risk will have decreased with the climate forecast. Second, because a decision maker does not know *a priori* what information will be be forthcoming, the decision to purchase or obtain additional information is risky. That is, if a decision maker purchases a forecast and the particular forecast does not change the decision from using only prior knowledge then a loss occurs from the decision to purchase the forecast (assuming the forecast has a positive cost). They state that these two risks "... may help explain the failure of decision makers to obtain information, even when the monetary returns appear to exceed the costs" (p. 245). In general, the few previous studies that have incorporated risk preferences into the decision making process have found that there is no monotonic relationship between the level of risk aversion and the value of climate information (Hilton, 1981; Mjelde and Cochran, 1988).

Mjelde and Cochran (1988) illustrate a methodology to obtain a lower and upper bound on the value of climate forecasts. The methodology is based on stochastic dominance techniques, and gives the bounds for admissible utility functions. Their results show that changing the decision maker's prior knowledge interacts with risk preferences in determining the bounds on climate forecast value.

Most of the previous studies valuing climatic information have assumed that the decision maker's prior knowledge of climatic conditions is identical to the historical probabilities of the climatic conditions. Bessler (1985) and Tversky and Kahneman (1983) have demonstrated that individuals are probably not accurate in their translation of historic events into probabilistic terms. A few studies have examined the effect of assuming different prior knowledges on the value of climate forecasts (Baquet et al., 1976; Doll, 1971; and Mjelde et al., 1988). In all cases, the value of climate forecasts were sensitive to the assumed prior knowledge. For example, two of the priors considered by Mjelde et al. (1988) are historical probabilities and the myopic view that last year's climatic conditions will occur this year. Assuming historical prior knowledge, perfect seasonal climate forecasts are worth $18.61/ac/yr in this east-central Illinois example for corn production. Whereas, their results assuming last year's prior knowledge indicated the forecasts are worth $28.46/ac/yr. Doll suggests that sensitivity analysis must be preformed to determine how the forecast value is affected by the assumed prior knowledge.

Summary of Micro Level Concepts

In this section four general determinants of information value have been presented. A review of the literature shows that, to at least some degree, each of these determinants have been examined within a climate forecasting framework. However, forecast accuracy has been the predominant attribute considered even through other attributes have been shown to be of similar economic importance. The general conclusion drawn from these studies is that climatic forecasts have potential value and that each of the information determinants can markedly affect the value of climate forecasts, although not in a systematic fashion (see Hilton, 1981). Specific attributes of each decision setting, however, can lead to a considerably different emphasis on the relative importance of the four general determinants.

SECTOR LEVEL CONCEPTS

Prior discussion has focused on the potential value of climate forecasts at the individual or firm level. But it is unlikely that the benefits of forecast information, if available, can be totally captured by one individual or a single firm. Further, because public funds are involved in research to improve climate forecasts and in the data collection efforts needed for that research, significant questions arise relating to forecast information value when large numbers of decision makers use the forecasts and to society's gain from expenditures of public funds. Although micro level analyses are relevant and necessary to our understanding of the potential value of climate forecasts, research efforts focused on aggregate levels also are required.

Sector level concepts are concerned with the effect of climate forecasts at the market rather than at the firm level. For example, how will an increase in relevancy of climate forecasts affect the market price for a given commodity? Furthermore, given a change in price, how is the welfare of both producers and consumers affected? The following section discusses an economic framework capable of addressing these and similar questions. In addition to economic concerns the dissemination of forecasts and political, social and legal issues also become relevant at the sector level of analysis. A brief consideration of the impact of these non-economic issues is provided following the discussion of sector economic issues. It is important to note that sector and micro concepts are inherently interrelated and the separation employed in this study is for ease of exposition. Indeed society's understanding of the potential for use of climate forecasts may be greatly enhanced when analytic techniques allow linking of analysis at different levels of aggregation (Sonka and Lamb, 1987).

Market Effects

The ability to provide climate forecasts in a form more relevant than current forecasts can be considered a technological advance. To the decision maker, the technological advance is in the form of "better" information being incorporated into the decision making process. Climate forecasting advances can be considered in an analogous manner to the more traditional technological advances embodied in machinery or genotypes. By definition, technological advances lower factor costs per unit of output. A simple, but informative methodology to examine the effect of lower factor costs is through graphical supply and demand analysis.

Figure 1 illustrates a market supply-demand diagram for a perfectly competitive market. A perfectly competitive market is characterized by price taking behavior by both buyers and sellers, which is normally a consequence of a large number of traders on both sides of the market. The horizontal axis represents the quantity of some commodity or service and the vertical axis represents price. The demand curve, D, gives for each price, P, the quantity that consumers are willing to purchase. Its negative slope indicates that buyers are willing to purchase more at lower prices. The supply curve, S, shows the quantity that producers are willing to provide to consumers at any given price. Supply curves represent the marginal costs of producing an additional unit of the commodity. The positive slope of the supply curve indicates that for producers to supply more of the commodity its price must rise. In Figure 1, the market equilibrium price (the price at which the market clears), P_o, and equilibrium quantity, Q_O, are given by the intersection of the supply and demand curves.

The concepts of consumer and producer surplus are useful in illustrating the effect of a technological advance. Consumer and producer surpluses are measures of the benefits of trade, scaled in objective units apart from individuals' subjective utilities. The authors acknowledge the various problems associated with using producer and consumer surplus. For a complete discussion see Just et al. (1982), and Pope et al. (1983). Illustration of the use of these concepts relative to climate issues can be found in Changnon et al. (1977).

Again considering Figure 1, for the very first unit purchased the demand price is OC but the actual price charged is OP_o hence a consumer surplus of $OC\text{-}OP_o=P_oC$ is gained on the first unit bought. Extending this argument to all successive units gives an aggregate consumer surplus of the triangle given by P_oBC. A corresponding argument applies to producer surplus. That is, for the first unit sold a price of OP_o is received but a cost of only OA is realized. For the first unit a producer surplus of $OP_o\text{-}OA=AP_o$ is realized. Again extending this argument to all successive units gives a producer surplus of P_oBA.

As noted earlier, technological advances lower factor costs per unit of output. At the market level this can be illustrated as an outward shift of the supply curve (with lower costs a producer is willing to supply more of a commodity at a given price). Assuming the demand curve is constant, Figure 1 shows the effect of a technological advance, namely a more reliable climate forecast, on a commodity which meets the necessary conditions for climate forecast information to be valuable. The long run effect of the climate information is to shift the supply curve from S to S', causing a change in both consumer and producer surplus. Before the technological change, consumers surplus was area a whereas, after the change it is a+b+c+g. This change in consumer surplus is an increase of b+c+g. Producer surplus changes from b+d to d+e+f. Producers lose the area b but gain the area e+f. The overall net benefit to producers depends on the magnitude of these two areas. Therefore, to determine the net effect of the change in producer surplus, estimates of supply and demand curves must be known for the industry.

The concepts of demand and supply curves and producer and consumer surplus are typically foreign to non-economists. Therefore, a reasonable question to ask is, why are they needed? Consider midwestern

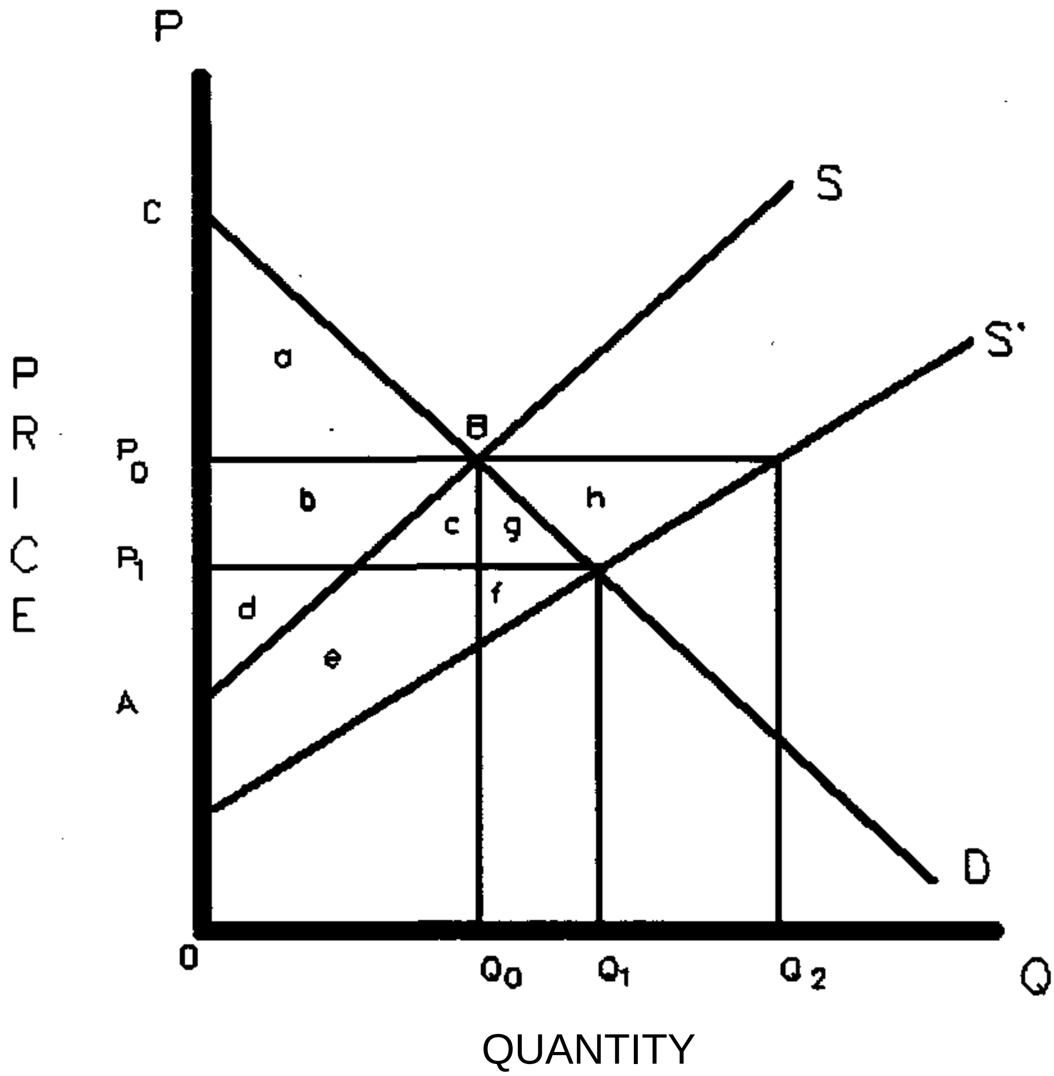

Figure 1. Effect on Consumer and Producer of on Increase in Relevancy of a Climate Forecast.

corn production and improvements in climate forecasting. If we know that each corn producer acting individually will gain on average $l,000/year, why not just multiply that gain by the number of corn producers in the midwest and call the answer the aggregate value of the improved climate forecast. The framework of Figure 1 allows us to illustrate the danger of ignoring price and quantity effects on valuing improvements in climate forecasts.

As one example, let's assume a researcher had computed the cost savings associated with the improved climate forecasts but ignored the effects of changes in quantity of corn produced or its price. Remember that in the pre-forecast situation, producer benefits were captured in areas b+d of Figure 1. If quantity and price are held constant but the corn supply curve shifts to S', producer benefits would be predicted to now include the areas b+c+d+e. In reality, corn prices and quantity will change, and as noted previously, producer surplus will be d+e+f. Therefore, even without actual estimates of demand and supply, ignoring the effect of the improved forecast on both quantity and price can be shown to produce erroneous estimates.

As a second illustration, let's consider the effect of recognizing the output enhancing nature of the forecast but ignoring the impact on price. In this situation, corn supply would be expected to increase to the level noted as Q_2 in Figure 1. Producer surplus is now said to be the amount b+c+d+e+f+g+h rather that the correct estimate of area d+e+f. Again, even though we don't know by how much the estimate of producer surplus is overstated, ignoring the price effect clearly results in an overstatement of the benefits.

Another reason for examining the framework shown in Figure 1 is that it illustrates the source of a second common misperception relative to the effects of technological change. That misperception relates to the notion that producers eventually (in a competitive market) must be hurt by the adoption of technology. Although demand and supply curves must be available to accurately assess the extent to which producers benefit or lose from the new technology, Figure 1 illustrates that the producer price is very likely to decline (unless the demand curve is horizontal). Often, because the market is competitive, the price decline is readily apparent and clearly a "bad" thing to producers. The "good" effects of the technology tend to be less observable to society. Particularly for commodities whose production is sensitive to climate events, attributing increases in output to the effect of the technology as opposed to outcomes due to chance fluctuations is difficult. Cost savings associated with the technology are even less apparent as they tend to be captured by accounting systems internal to the firm and are not part of public information systems.

The combined effect of these forces is that it is relatively easy for the public to observe the negative changes associated with the technological advances, but relatively more difficult to observe its positive contributions. This disparity of perceptions doesn't affect the true economic value of the innovation but may influence society's desire to support the development of enhanced technologies, such as in this case, climate forecast information. Given that it is easy for such misperceptions to occur, careful analysis of sector level impacts of improved forecasting capabilities is especially important.

Although there has been relatively little research relating to sector level effects of climate forecasts, a few studies have addressed market effects of climate forecasts (Lave, 1963; Greenburg, 1976; Johnson and Holt, 1986; Paltridge, 1985). These studies were concerned primarily with the affect on the producer and did not address benefits generated to consumers. Paltridge (1985) presents a highly simplified agricultural example to illustrate that climate forecasts may be detrimental to producers when market effects are considered. In a much more rigorous economic study, Lave (1963) estimated the price demand elasticity for the raisin industry. Statistical analysis indicated that, because the raisin industry faces an inelastic demand, climate forecasts will reduce the total industry's producer surplus. Johnson and Holt (1986) provide a slightly different theoretical framework than presented here for market evaluation of climate information. Their framework relies upon the rational expectations hypothesis and as such is difficult to utilize in applied research. Greenberg assumes that demand is completely elastic (a horizontal demand curve), therefore, there are no added benefits to consumers from resulting price reductions. Failure to address and estimate benefits to consumers from climate forecasts represents a substantial gap in our knowledge.

One final point concerning the effect of technological advance is the concept of Schumpeterian profits. This concept relates to the perception that earlier adopters of technological advances have greater profits than do non-adopters. The earlier adopters benefit from lower costs, but in a perfectly competitive market, their output only slightly affects price. As more and more decision makers adopt the technological advance, Schumpeterian profits are decreased and eventually are driven to zero. The static analysis in Figure 1 does not allow for the dynamic analysis of Schumpeterian profits.

The notion of Schumpeterian profits is especially interesting for markets where international competition is likely. As shown by Edwards and Freebairn (1984) and Sonka (1986), analysis of winners and losers for internationally traded commodities is greatly affected by the party who is the early adopter of the technology. Producers in a nation without the capability to aggressively exploit cost-saving technologies can be severely disadvantaged by technology adoption among producers in competitor nations.

Communication Concepts

Earlier three elements of flexible decision making environments were presented. The third element was that management must have the capability and willingness to adopt a flexible management strategy which allows integration of climate forecasts into the decision process. An important component of this integration is the communication channels between the forecaster and the decision maker. Getting the forecast from the forecaster to the decision maker provides a potential problem area, especially with publicly issued forecasts. Getz (1978) states that

> "Dissemination of available weather information was found to be the major problem in New Jersey's agricultural weather service. Weather information was being prepared by the NWS for New Jersey agriculture, but was not reaching the user" (pp. 1303-1304).

This problem arose because the agricultural users relied on radio stations for the forecasts, but the radio stations did not subscribe to the NWS forecast service. Rather, the radio stations relied on wire services to transmit the forecasts. Publicly issued forecasts are faced with this potential problem of dissemination of the forecasts. For private forecasts, dissemination should be less of a problem, because of the opportunity for the decision maker and forecaster to interact about the "best" way to provide the forecast. Other communication issues involve the preferred method of obtaining forecasts and preferred time of day the forecast is received (Getz, 1978; Brown and Collins, 1978; Rench and Makosky, 1978).

An additional communication concept is the necessary cooperation between the decision maker and the forecaster. Roth (1963), Maunder (1973), Davis and Nnaji (1982), Stuart (1982), and Prior and King (1981) argue that for climate information to be in a relevant form, cooperation between both forecaster and decision maker is necessary. The forecaster must be aware of the decision process environment and the decision maker must be aware of the contents of the forecasts. Schnee (1977) also argues that education is necessary on decision making techniques which incorporate stochastic forecasts.

Previous studies employing survey techniques indicate that current climate forecasts are being utilized by the public (Easterling, 1986; Stewart et al., 1984; Vining et al., 1984; Brown and Collins, 1978; Lamb et aL, 1984,1985; Krawitz and Newhouse, 1978; Rench and Makosky, 1978). For example, Getz (1978) reported that 91% of the respondents to his New Jersey survey checked a daily weather forecast. These studies indicate that both forecasters and decision makers are aware of the communication channels and have overcome, at least partly, some of the difficulties associated with communication of forecasts.

Political, Social, and Legal Issues

Glantz (1977, 1979,1982) emphasizes the need for analyses to separately identify non-meteorological and meteorological factors to obtain a more accurate assessment of the value of climate forecasting to society. Major considerations are the political, social, and legal constraints imposed on the decision environment. Consideration of such constraints provides a more accurate valuation of climate forecasts. Changnon and Vonnhame report on the use of a seasonal precipitation forecast in an actual economic/political decision making context.

Earlier the concepts of consumer and producer surplus were used to illustrate the potential benefits of climate forecasting in a perfect competitive market. Government intervention in the form of price supports, floors, and ceilings, quotas, taxes, and subsidies affect both the magnitude and the distribution of the economic benefits. As an example consider Figure 2, in which a price floor of P_2 has been imposed on the market. In this case, the price floor does not allow the market price to be lower than P_r (This example also assumes that quantity is restricted. In reality at a price of P_2 producers would want to supply more than Q_2 Including analysis of this addition supply in the example complicates the issue, but does not change the point of the example that government intervention affects the distribution of wealth between producers and consumers.) Before the advent of an improved climate forecast, consumer and producer surpluses are given by areas a and b, respectively, and the quantity of the good demanded by consumers is Q_r. The area d represents the loss of consumer and producer surplus resulting because of the price floor. The advent of improved climate forecasts leads to a shift in the supply curve from S to S', Because of the price floor, both price and quantity do not change. Consumer surplus therefore, does not change. Producer surplus, however, increases from b to b+c. The loss in both consumer and producer surplus caused by the price floor increases to area d+e after the forecasts are introduced. This simple example illustrates the importance of government intervention in determining the magnitude and distribution of the benefits derived from technological advances.

Glantz (1977) conducted a study on the political, social, and economic implications of a long range forecast for the West African Sahel. He states

> "This preliminary assessment leads to the tentative conclusion that, given the national structures in the Sahelian States in which a potential technological capability would be used, the value of a long-range forecast, even a perfect one, would be limited. It appears, however, that its value could be greatly enhanced if its implementation were to be coupled with the removal of the numerous social, political, and economic obstacles ..." (pp. 156-157).

Although this study was conducted in an underdeveloped area, it does indicate the effect that social and political constraints have on the use and value of climate forecasts. Suchman et al. (1979) found several noneconomic reasons for subscribing to forecasting services. Noneconomic reasons given for subscribing to a forecast service included convenience, increased sense of security, and appearance to both job superiors and the public.

Questions concerning the liability for erroneous forecasts were addressed by Weiss (1982). For example, is the federal or state government liable for erroneous forecasts? In the cases reviewed by Weiss, the courts found liability for an incorrect forecast in only one case. Liability was found when the plaintiff communicated his special needs for the forecast directly to the state employee. The court distinguished between the dissemination of public information of a non-personal nature from the one-to-one basis in this case. Weiss concludes

> "... that at least in the near-term, governmental liability for incorrect seasonal forecasts should be a negligible problem. It will not constrain the development, dissemination and use of such forecasts" (p. 516).

FINAL REMARKS

The diversity of the concepts summarized in this paper exemplify the difficult and complex nature of valuing the socioeconomic benefits of climate forecasts. Sonka et. al. (1986) argue that a multi-disciplinary research approach is the appropriate means to value climate forecasts. Mason (1978) also argues for the need of substantial programs at both the national and international levels. For a discussion of international implications associated with climate forecasting, see Weiss (1981).

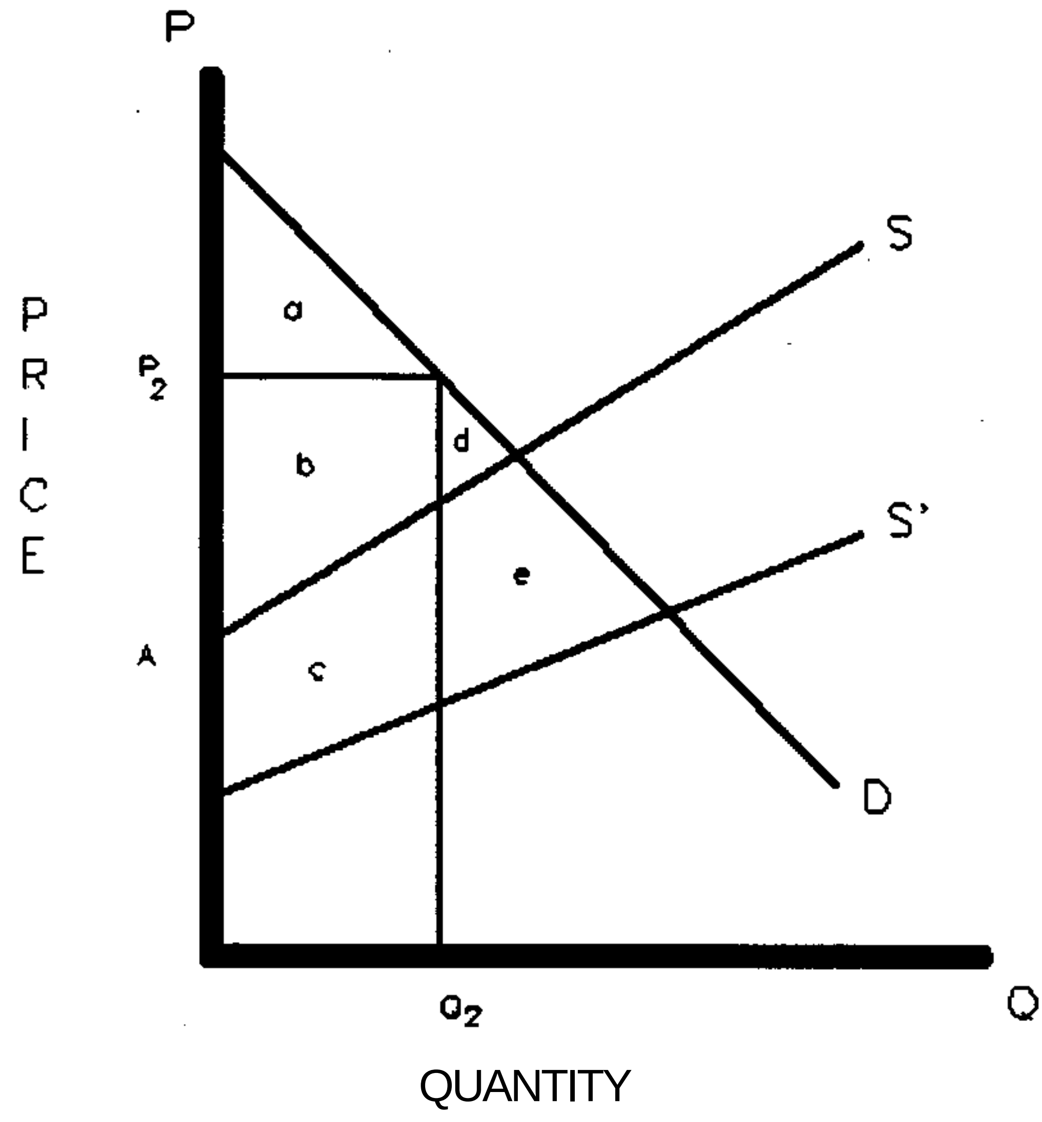

Figure 2. Effect of a Price Floor on Consumer and Producer Surplus, Given an Improved Climate Forecast.

Three issues are addressed before discussing research implications. First, this review has been concerned with management and the value of climate forecasts in a managerial setting. The concepts introduced in this review also apply to individuals in their everyday decision making process. That is decisions pertaining to recreation, lawn care, etc. are affected by both weather and weather forecasts. Second, development and dissemination costs must be considered. Over sixty percent of the respondents of Brown and Collins (1978) survey indicate either state or federal governments should pay dissemination costs. Thirdly, given current attitudes toward weather and climate forecasts it may be necessary to ask "What is necessary to convince decision makers to utilize climate and weather forecasts?" That is what steps are necessary to assure decision makers that the forecasts are reliable and that the forecasts will improve their decision making process.

This review of previous studies indicates that current and improved climate and weather forecasts do possess economic value. Further, the process of valuing such forecasts is a complex issue. Several gaps in our knowledge concerning the economic value of such forecasts become apparent when reviewing the literature. The need to understand the sector level affects of climate and weather forecast systems and a methodology to link micro and sector analysis cannot be overstated. To assess the overall economic impact of improved climate and weather on a country's economy, sector analysis is a necessity. This analysis must consider both producers and consumers. Further, these market affects need to extend beyond perfectly competitive markets. Determining the affect of the various forecast design characteristics on several different industries would allow for more general statements to be made concerning the characteristics. The needed analyses must include characteristics other than accuracy. Characteristics such as lead time, spatial resolution and specificity may prove to be as important as predictive accuracy. Finally, and most importantly, the proper time to assess the value of a climate or weather forecast is before the forecast becomes operational. Especially if conducted in multi-disciplinary contexts, such ex-ante valuations can provide information on the most beneficial forecast designs to be investigated.

References

Andrews, J.F. 1982. "Improved Weather Forecasts: How One Gas Utility Benefited." Bull. Am. Met. Soc. 63, 1035-1039.

Armstrong, J.S. 1985. Long-Range Forecasting: From Crystal Ball to Computer. John Wiley & Sons. N.Y.

Baquet, A.E., AN. Halter, and F.S. Conklin. 1976. "The Value of Frost Forecasting: A Bayesian Appraisal." Am. J. Agric. Econ., 58, 511-520.

Bergen, W.R. and AH. Murphy. 1978. "Potential Economic and Social Value of Short-Range Forecasts of Boulder Windstorms." Bull. Am. Met. Soc., 59, 29-44.

Bessler, D. 1985. "Forecasting in Risk Research". Risk Analysis for Agricultural Production Firms: Concepts, Information Requirements, and Policy Issues. Staff Paper 85-85. Dept. of Agric. Econ., Michigan State U., East Lansing, MI. pp. 95-106.

Brown, T.J. and A.J. Collins. Sept. 1, 1978. "Large Commercial Family Farms - Informational Needs and Sources." Report, National Extension Study Committee, Agricultural Economics, University of Missouri - Columbia.

Brown B.G., R.W. Katz, and AH. Murphy. 1986. "On the Economic Value of Seasonal Precipitation Forecasts: The Fallowing/Planting Problem." Bull. Am. Met. Soc, 67, 833-841.

Byerlee, D.R. and J.R. Anderson. 1969. "The Value of Predictors of Uncontrolled Factors in Response Functions." Aust. J. Agric. Econ., 13, 118-127.

Byerlee, D.R. and J.R. Anderson. 1982. "Risk, Utility and the Value of Information in Farmer's Decision Making." Rev. Mark. and Agric. Econ., 50, 231-246.

Changnon, S.A Jr., R.J. Davis, B.C. Farhar, J.E. Hass, J.L. Ivans, M.V. Jones, D.A Klein, D. Mann, G.M. Morgan, S.T. Sonka, E.R. Swanson, C.R. Taylor, and J. Van Blokland. 1977. Hail Suppression: Impacts and Issues. Illinois State Water Survey, Champaign, IL.

Changnon, S.A Jr., and D.R. Vonnhame. 1986. "Use of Climate Predictions to Decide A Water Management Problem." Wat. Resources Bull. 22, 649-652.

Collins, G.F. "A Severe Weather Service for Industry." 1956. Bull. Am. Met. Soc., 37, 514-516.

Davis, D.R. and S. Nnaji. 1982. "The Information Needed to Evaluate the Worth of Uncertain Information, Predictions, and Forecasts." J. Applied Met., 21, 461-470.

Doll, J.P. 1971. "Obtaining Preliminary Bayesian Estimates of the Value of a Weather Forecast." Am. J. Agric Econ., 53, 651-655.

Dryer, J.A, and W. Baier. 1981. "The Use of Weather Forecasts to Improve Haymaking Reliability." Agric Met., 25, 27-34.

Easterling, W.E. 1986. "Subscribers to the NOAA Monthly and Seasonal Weather Outlook." Bull. Am, Met. Soc. 67, 402-408.

Easterling, W.E., and J.W. Mjelde. 1987. The Importance of Seasonal Climate Prediction Lead Time in Agricultural Decision Making." Agric. and Forest Met., 40, 37-50.

Edwards, G.W. and J.W. Freebairn. 1984. The Gains From Research into Tradable Commodities." Am. J. Agric. Econ., 66, 41-49.

Gandin, L.S., Yo Ya Zhukcvskiy, and T.M. Bruncva. 1980. "On an Economically Optimum Combination of Weather Forecasts. Atmos. and Oceanic Phys., 15, 403-407.

Getz, R.R. 1978. "A Survey of New Jersey's Agricultural Weather Service Users." Bull. Am. Met. Soc., 59, 1297-1304.

Glantz, M.H. 1977. "The Value of a Long-Range Weather Forecast for the West African Sahel." Bull. Am. Met. Soc. 58, 150-158.

Glantz, M.H. May, 1979. "Saskatchewan Spring Wheat Production 1974: A Preliminary Assessment of a Reliable Long-Range Forecast." Climatological Studies, No. 33, National Center for Atmospheric Research, Boulder, CO.

Glantz, M.H. 1982. "Consequences and Responsibilities in Drought Forecasting: The Case of Yakima, 1977." Wat. Resources Res., 18, 3-13.

Gleeson, T.A 1960. "A Prediction and Decision Method for Applied Meteorology, Based Partly on the Theory of Games." J. Met., 17, 116-121.

Greenberg, J. 1976. "Economic Benefits of Improved Meteorological Forecasts." In Weather Forecasting and Weather Forecasts: Models Systems and Users, Boulder, Colo.: National Center for Atmospheric Research. 2, 608-629.

Hallanger, N.L. 1963. "The Business of Weather: Its Potential and Uses." Bull. Am. Met. Soc. 44, 63-67

Hilton, R.W. 1981. "The Determinants of Information Value: Synthesizing Some General Results." Management Sci., 27, 57-64.

Hofing, S.T., S.T. Sonka, and S.A Changnon, Jr. 1987. "Enhancing Information Use in Decision-Making: Agribusiness and Climate Information." Final Report NSF IS 86-60497, Agricultural Education and Consulting, Champaign, IL.

Johnson, S.R. and M.T. Holt. 1986. "The Value of Climate Information." in Policy Aspects of Climate Forecasting. R. Krasnow, ed. Resources For the Future, Renewable Resources Division, Wash. D.C., 53-78.

Just, R.E., D.L. Hueth, and A Schmitz. 1982. Applied Welfare Economics and Public Policy. Prentice - Hall Inc., Englewood Cliffs, N.J.

Katz, R.W., B.G. Brown, and AH. Murphy. 1987. "Decision-Analytic Assessment of the Economic Value of Weather Forecasts: The Fallowing/Planting Problem." J. of Forecasting, 6, 77-89.

Katz, R.W., AH. Murphy, and R.L. Winkler. 1982. "Assessing the Value of Frost Forecasts to Orchardists: A Dynamic Decisionmaking Approach." J. Appl. Met., 21, 518-531.

Krawitz, L. and H. Newhouse. 1978. "A Survey of External Users of NWS Information." Bull. Am. Met. Soc., 59, 1288-1296.

Lamb, PJ. 1981. "Do We Know What We Should be Trying to Forecast - Climatically?" Bull. Am. Met. Soc. 62, 1000-1001.

Lamb, P.J., S.T. Sonka, and S.A. Changnon, Jr. 1984. "The Present and Potential Use of Climate Information by the United States Private Agricultural Sector." Final Report NSF ATM 81-16615, Illinois State Wat. Survey, Champaign, IL.

Lamb, PJ., S.T. Sonka, and S.A Changnon, Jr. 1985. Use of Climate Information by U.S. Agribusiness. NOAA Technical Report NCPO 001. U.S. Department of Commerce, National Oceanic and Atmospheric Administration. Rockville, MD., 67 pp.

Lave, L.B. 1963. The Value of Better Weather Information to the Raisin Industry." Econometrica. 31, 151-164.

Lovell, C.A.K. and V.R. Smith. 1985. "Microeconomic Analysis." in Climate Impact Assessment Kates et al. editors, John Wiley and Sons, N.Y., pp. 293-322.

Mason, BJ. 1978. "The World Climate Programme." Nature, 276, 327-328.

Maunder, W.J. 1973. "Weekly Weather and Economic Activities on a National Scale: An Example Using United States Retail Trade Data." Weath., 28, 2-18.

Mazzacco, M.A 1989. "Valuing Climate Information for Midwestern Grain Producers." Unpublished Ph.D. Dissertation, University of Illinois. Champaign, Illinois, 178 pp.

Merkhofer, M.W. 1977. "The Value of Information Given Decision Flexibility." Management Sci., 23, 716-727.

Mjelde, J.W. 1985. "Dynamic Programming Model of the Corn Production Decision Process with Stochastic Climate Forecasts." Unpublished Ph.D. Dissertation, University of Illinois. Champaign, Illinois., 265 pp.

Mjelde, J.W. and M. Cochran. 1988. "Obtaining Lower and Upper Bounds on the Value of Seasonal Climate Forecasts Utilizing Stochastic Dominance Procedures." Forthcoming in West. J. Agr. Econ. Dec.

Mjelde, J.W. and B.L. Dixon. 1989. "Valuing Lead Time of Forecasts in Dynamic Production Systems: Impact of Prior Beliefs." Paper to be presented at the 6th IFAC/SEDC Symposium on Dynamic Modelling and Control of National Economies. Heriot-Watt University, Edinburgh, June 27-29.

Mjelde, J.W., B.L. Dixon, S.T. Sonka, and P.J. Lamb. 1988. "Valuing Forecast Characteristics in a Dynamic Agricultural Production System." Forthcoming in Am. J. Agric. Econ. August 1988.

Mjelde, J.W. and S.J. French. 1987. "Selected Review of Literature Concerned with Socioeconomic Issues of Climate/Weather Forecasting with Additional References." Staff Paper, Dept. of Agric. Econ. DIR 87-1 SP-5, Texas A&M University, College Station, TX.

Mjelde, J.W., S.T. Sonka, B.L. Dixon, and P.J. Lamb. 1986. "Integration of Dynamic Programming and Simulation Models to Value Lead Time of Information Forecasting Systems." Staff Paper Dept. of Agric. Econ. DIR 86-1 SP-4, Texas A&M University, College Station, TX.

Murphy, A.H. 1976. "Decision Making Models in the Cost-Loss Ratio Situations and Measures of the Value of Probability Forecasts." Mon. Weath. Rev., 104, 1058-1065.

Murphy, A.H. 1977. "The Value of Climatological, Categorized, and Probabilities Forecasts in the Cost-Loss Ratio Situation." Mon. Weath. Rev., 105, 803-816.

Murphy, A.H. and J.C. Thompson. 1977. "On the Nature of the Nonexistence of Ordinal Relationships Between Measures of the Accuracy and Value of Probability Forecasts: An Example." J. Appl. Met., 16, 1015-1021.

Murphy, A.H., R.W. Katz, R.L. Winkler, and W.R. Hsu. 1985. "Repetitive Decision Making and the Value of Forecasts in the Cost-Loss Ratio Situation: A Dynamic Model." Mon. Weath. Rev., 113, 801-813.

Nelson, R.R., and S.G. Winter, Jr. 1964. "A Case Study in the Economics of Information and Coordination: The Weather Forecasting System." Quart. J. Econ., 78, 420-441.

Paltridge, G.W. 1985. "The Value of Climate Forecasting." Geophysical Surveys., 7, 273-290.

Peel, D.S., S.T. Sonka, and J.W. Mjelde. 1988. "Accuracy and Inaccuracy as Determinants of the Value of Forecasts." Working Draft, Dept. of Ag. Economics, University of Illinois.

Pope, R., J.P Chavas, and R. Just. 1983. "Economic Welfare Evaluation for Producers under Uncertainty." Am. J. Agric. Econ., 65, 98-107.

Price, S. 1949. "Thunderstorm Today?" Weatherwise, 2, 61-67.

Prior, M.J. and E.G.E. King. 1981. "Weather Forecasting for Construction Sites." Met. Magazine. 110, 260-266.

Rench, W.E. and F. Makosky. 1978. Utility of Agricultural Weather Services in the Mid-South. NOAA Tech. Memo, NWS SR-95, Scientific Services Div., Southern Region, Fort Worth, Texas.

Roth, R.J. 1963. "Further Application of Weather Information." Bull. Am. Met. Soc., 44, 72-74.

Russo, J.A. 1966. "The Economic Impact of Weather on The Construction Industry of the United States." Bull. Am. Met. Soc., 47, 967-972.

Schnee, J.E. 1977. "Predicting the Unpredictable: The Impact of Meteorological Satellites on Weather Forecasting." Technological Forecasting and Social Change, 10, 299-307.

Sonka, S.T. 1985. "Information Management in Farm Production." J. of Computers and Electronics in Agriculture, 1, 75-85.

Sonka S.T. 1986. "Competition, Technology, and Illinois Agriculture." Illinois Research, College of Agriculture, University of Illinois at Urbana-Champaign. 28, 8-10.

Sonka, S.T. and P.J. Lamb. 1987. "On Climate Change and Economic Analysis." Climatic Change, 11, 291-311.

Sonka, S.T., P.J. Lamb, S.A Changnon, Jr., and A Wiboonpongsee. 1982. "Can Climate Forecasts For the Growing Season be Valuable to Crop Producers: Some General Considerations and an Illinois Pilot Study." J. Appl. Met.. 21, 471-476.

Sonka, S.T., P.J. Lamb, S.E. Hollinger, and J.W. Mjelde. 1986. "Economic Use of Weather and Climate Information: Concepts and an Agricultural Example." J. of Climatology., 6, 447-457.

Sonka, ST., J.W. Mjelde, PJ. Lamb, S.E. Hollinger, and B.L. Dixon. 1987. "Valuing Climate Forecast Information." J. Climate and Appl. Met., 26, 1080-1091.

Stewart, T.R., R.W. Katz, and A.H. Murphy. 1984 "Value of Weather Information: A Descriptive Study of the Fruit-Frost Problem." Bull. Am. Met. Soc., 65, 126-137.

Stuart, A 1982. "On the Economic Value of Probability of Precipitation Forecasts in Canada." J. Appl. Met., 21, 495-498.

Suchman, D., B.A. Auvine, and B.H. Hinton. 1979. "Some Economic Effects of Private Meteorological Forecasting." Bull. Am. Met. Soc., 60, 1148-1157.

Suchman, D., B.A Auvine, and B.H. Hinton. 1981. "Determining Economic Benefits of Satellite Data in Short-Range Forecasting." Bull. Am. Met. Soc., 62, 1458-1465.

Thompson, J.C. 1962. "Economic Gains from Scientific Advances and Operational Improvement in Meteorological Prediction." J. Appl. Met.. 1, 13-27.

Thompson, J.C. 1972. "The Potential Economic Benefits of Improvements in Weather Forecasting." Department of Meteorology, California State University, San Jose. Final Report (NASA Grant NGR 05-046-005).

Tomek, W.G. and K.L. Robinson. 1981. Agricultural Product Prices (2nd Edition) Ithica, N.Y.: Cornell University Press.

Tversky, A. and D. Kahneman. 1983. "Extensional vs. Intuitive Reasoning: The Conjection Fallacy in Probability Judgement." Psych. Rev., 90, 293-315.

Vining, K.C., C.A Pope III, and W.A. Dugas, Jr. 1984. "Usefulness of Weather Information to Texas Agricultural Producers." Bull. Am. Met. Soc., 65, 1316-1319.

Wallace, J.E. 1971. "The Uses of Private Weather Services." Bull. Am. Met. Soc. 52, 548-550.

Weiss, E.B. 1981. "International Implications of Seasonal Climate Forecasting." Stanford J. Int. Law. 17, 315-345.

Weiss, E.B. 1982. "The Value of Seasonal Climate Forecasts in Managing Energy Resources." J. Appl. Met., 21, 510-517.

Wilks, D.S., and AH. Murphy. 1985. The Value of Seasonal Precipitation Forecasts in a Haying/Pasturing Problem in Western Oregon." Mon. Weath. Rev., 113, 1738-1745.

Wilks, D.S., and AH. Murphy. 1986. "A Decision-Analytic Study of the Joint Value of Seasonal Precipitation and Temperature Forecasts in a Choice-Of-Crop Problem." Atmos. - Ocean., 24, 353-368.

Winkler, R.L., AH. Murphy, and R.W. Katz. 1983. "The Value of Climate Information: A Decision-Analytic Approach." J. of Climatology. 3, 187-197.

World Meteorological Organization. 1968. "Economic Benefits of Meteorology." World Met. Org. Bull.. 18, 181-186.

World Meteorological Organization. 1978. "World Climate Programme." World Met. Org. Bull.. 27, 276-278.