This paper discusses ongoing research intended to develop a clearer understanding of the impact of weather modification on a portion of the agricultural sector of the U.S. economy, the feed-livestock complex. The research framework models the interactive effects of changing weather, technology, government policies, and demand on market prices. Supply and demand relations must be estimated and solved within the context of a simultaneous equation econometric model. Within the model, crop yield response relations must be estimated at an appropriate level of geographical aggregation to ensure uniform measurement of weather modification effects. An econometric technique, based on the use of binary variables, is proposed as means for selecting geographical aggregates. The transmission of the "weather effect" to the agricultural sector is accomplished in the supply-demand model. Benefits accruing to various market participants may then be identified under alternative scenarios of weather modification.

1. INTRODUCTION

Climatic and weather variability are important features of midwest agriculture. Recent extremes in weather and concern over possible shifts in climatic patterns have led to an awareness that a more in-depth understanding of climatic and weather related impacts on society by sectors of the economy is essential.

This paper discusses ongoing research intended to develop a clearer understanding of the impact of weather modification on a portion of the agricultural sector of the U.S. economy, the feed-livestock complex. The research framework models the interactive effects of changing weather, technology, government policies, and demand on market prices. Supply and demand relations are estimated and solved within the context of a simultaneous equation econometric model. Discussion here focuses on: (1) alternative approaches for disentangling the effects of technology and weather on crop yields using disaggregated data; (2) transmission of the "weather effect" through the agricultural sector; and (3) the benefits from successful weather modification.

2. MODELING YIELD RESPONSE

To gain perspective on existing knowledge about yield response, earlier studies were reviewed and compared with respect to the selection of explanatory variables, estimated coefficients, and units of observation (Table I). This paper cannot explore all aspects of the studies; instead, focuses on the definition of the appropriate level of aggregation for the geographical area under study. Aggregation bias is an important concern in analyzing response to weather modification.

The studies cited in Table I display little consistency in level of aggregation of the empirical investigations. (Compare notations under last column, "unit of study."). The definition of the geographical area from which the data are drawn is not the same across studies, but ranges along a continuum from the national aggregate to the individual farm. At the highest level of aggregation, investigations involve variables calculated as U.S. national averages (e.g., Menz and Pardy, 1983). At the next level are regional aggregates, such as the Great Plains or Corn Belt, or subsets of states within those regions, (e.g., Thompson, 1969, 1970). State level data represents the next tier (e.g., Changnon and Neill, 1967). Crop reporting districts on a sub-state basis were used by Huff and Neill (1982). At the lowest level of aggregation are studies by county (Nelson and Dale, 1978a, b) and then individual farm data (Swanson and Nyankori, 1979). Are results of the studies, in terms of their explanation of the relative importance of technology and weather in affecting yield behavior over time, invariant with respect to level of aggregation?

The studies' results do differ, especially with respect to the identity of important explanatory variables (Table I). The empirical estimates of response coefficients across studies vary as well in the relative importance of variables. Both types of differences may be attributable to differences in level of aggregation. Before introduction of a systematic statistical framework for dealing with possible biases which may arise because of aggregation, illustrations of these effects are offered.

Very different pictures of yield behavior often emerge when the results of studies are compared. For example, the work of Menz and Pardy (1983) at the national aggregate level suggests that corn yields did reach a plateau over the 1970s. In contrast, the farm level study of Swanson and Nyankori (1979) indicated no such levelling off. These differences may be
When acreage in the unit under study remains marginal lands on national average yields, which bears out the depressing effects of harvested each year, has a negative sign, brought into production. Since yields on the coefficient of an explanatory variable is reduced. In the Menz and Pardy study, earlier base, the national average figure these parcels were lower than on the 1970s as acreage planted and harvested yields may appear to have levelled off over aggregation. From the national perspective, attributable directly to the level of weather data were used in the same manner. 

Table 1. Selected Research on the Effects of Technology and Weather on U.S. Crop Yields.

<table>
<thead>
<tr>
<th>Technology</th>
<th>Method</th>
<th>Precipitation</th>
<th>Temperature</th>
<th>Area</th>
<th>Unit of measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hendricks-Scholl</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Changnon-Neill</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Michelson</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Thompson, 1969</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Thompson, 1970</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Huff-Changnon</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Houck-Gallagher</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Butell-Naive</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Nelson-Dale, 1978a</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Nelson-Dale, 1978b</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Swanson-Nyankori</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Huff-Neill</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Pope-Heady</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
<tr>
<td>Menz-Pardey</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>Corn of pld. price</td>
</tr>
</tbody>
</table>

Explanation of Symbols

1. Weather variables: PP: Preseason precipitation (September-April); MP: May precipitation; JyP: July precipitation; JP: June precipitation; AT: August temperature.

2. Trend Precipitation Temperature
   a. Temperature-rainfall interactions were included for each month, and also weekly weather data were used in the same manner.
   b. Region consists of states Ohio, Indiana, and Ohio, period 1890-1939.
   c. Regions consist of counties in Illinois.
   d. Region consists of Eastern Washington and Northern Idaho.
   e. Five state region, the states are Illinois, Indiana, Iowa, Missouri, and Ohio.
   f. Interactions of temperature and precipitation with technology for the months of June, July, and August were used.
   g. National level.
   h. A linear time trend (T) was used in three different forms: 1. T increased by one each year from the beginning of the period through 1960, after it became constant. 2. T was zero through 1960, began with a one in 1961, and increased each year by one, and 3. T was square of the second form.

3. Regional variations are explained solely as a function of changes in technology and weather, and no levelling off is observed.

3. REGIONAL VARIATIONS

That the level of aggregation may influence the results of a study intended to describe the impact of weather and technology on crop yields is an important consideration in evaluating the effects of weather modification on yields. Weather modification as currently discussed would occur over a relatively limited geographical region. Thus, the response coefficients should pertain to that region to assess accurately effects of modification, since weather events may have
differential effects from different regional perspectives.

Such regional differences have been recognized in, for example, the analysis of soil erosion potential. Several distinct geographical regions within one state may be designated as having different erosive potentials because of differences in soil and topography. Such environmental differences may then also affect general yield levels, such that, for example, corn yields in east central Illinois are on average higher than those in more northerly areas, although the weather and technology may be relatively uniform. Consequently, a study should seek to account for these types of structural differences in order to isolate the effect of technology and weather on crop yields.

In the majority of the studies which use multi-state or state level data, no allowance is made for differences in response coefficients which may arise because of differences in resource endowment (e.g., soil quality) and economic structure (e.g., farm size) across and within geographic regions. Man-made political boundaries do not necessarily provide an adequate measure of aggregating data since they do not necessarily coincide with changes in agronomic and economic conditions relevant to variation in crop yields. Historically, most studies have taken this approach because data are collected by government agencies which usually operate within state boundaries. However, the US Department of Agriculture has defined Crop Reporting Districts (CRD) which correspond more closely to desirable agronomic boundaries than do traditional political units. Typically, each state has nine such districts; data on crop yields and acreages and on weather and economic variables are generally available for each district. Thus, CRD data represent a more useful aggregation unit for studying the effects of weather modification.

Use of CRD data still assumes that response coefficients are uniform over farms within the district. While this assumption is probably not strictly correct, disaggregation to farm level is costly and may not ultimately increase the amount of useful information available to the researcher. With this limitation, it seems reasonable to suppose that response coefficients might differ among these districts. Thompson (1969, 1970) recognized that such differences might exist on an inter-state basis, but, as argued, state units may still mask important intra-state variations. Huff and Neill (1982) used CRD data for their study, but their method of aggregation may be improved.

To account for inter-district differences arising out of agronomic and economic environmental variation, a systematic statistical framework for analysis may be based on the analysis of variance, implemented in regression analysis through the use of binary (dummy or zero-one) variables. This approach attempts to measure differences among regional aggregates without explicitly identifying the factors which lie at the root of the differences. In yield response studies the identification of the genesis of such underlying differences is less important than accounting for their existence. A "hierarchy" of model specifications can be constructed under varying degrees of similarity across regional units. The existence of these differences may then be tested to determine their significance in some statistical sense, and so should be allowed for in the modeling effort. At present, inter-regional differences are assumed constant across time, although the framework may be easily adapted to compensate for variation over years as well as across regions.

4. MODEL FORMULATION

To facilitate empirical investigation, models of inter-regional or cross-sectional (as opposed to time series) variation may be defined from the most restrictive hypothesis about response coefficients to the least. The general statistical model for this procedure may be written as:

\[ Y_{it} = \beta_0 + \sum_{k=1}^{K} \beta_k X_{kit} + \epsilon_{it} \]  

where \( i = 1, \ldots, N \) refers to a cross-sectional unit and \( t = 1, \ldots, T \) refers to a given time period. Thus, \( Y_{it} \) is the value of the dependent variable (crop yield) for cross section unit (CRD) \( i \) at time \( t \) and \( X_{kit} \) is the value of the \( k \)th explanatory variable (technology, weather, etc.) for unit \( i \) at time \( t \). The stochastic error term \( \epsilon_{it} \) is initially assumed to have mean zero and constant variance and be independent across units (i.e., \( E(\epsilon_{it}\epsilon_{ij}) = \sigma^2, \epsilon_{it} = 0 \) for \( i \neq j \) ). The \( \beta_k \) are unknown response coefficients; in the most general case, they may be different for different units \( i \) at different times \( t \); here only differences over \( i \) are considered and so the \( t \) subscript may be dropped. Using this model, the hierarchy may be defined as below.

I. Response coefficients do not differ over units:

\[ Y_i = \beta_0 + \sum_{k=1}^{K} \beta_k X_{ki} + \epsilon_i. \]  

II. There are differences in the level of response (intercept) over units but not among the (slope) coefficients associated with the individual explanatory variables:

\[ Y_i = \beta_0 + \sum_{k=1}^{K} \beta_k X_{ki} + \epsilon_i. \]  

III. Both intercept and slope coefficients differ over time, and the disturbances (\( \epsilon_i \)) associated with different units are correlated at a given point in time but not over time:
These models may be applied to test contemporaneous errors:

\[ y_i = \beta_0 + \sum_{k=1}^{K} \beta_{k} x_{ki} + e_i. \] (4)

where the variance of the disturbance now reflects the correlation across units (E(\(e_{ij}e_{lj}\)) = 0 for i ≠ j).

IV. Both slopes and intercepts differ across units, with no relations among contemporaneous errors:

\[ y_i = \beta_{0i} + \sum_{k=1}^{K} \beta_{ki} x_{ki} + e_i. \] (5)

These models may be applied to test hypotheses about the nature and extent of possible differences among units.

5. MODEL APPLICATION

In applying these models, the null hypothesis may be taken to be the model of no cross-sectional differences (model I) and the alternative may be formulated as any one of models II, III, or IV. In Thompson's studies, model II was taken as the maintained hypothesis, implying differences in overall yield levels across units (states in his formulation). However, the validity of that assumption may be tested statistically by comparing the explanatory power of model I to that of model II using a standard F test (involving the ratio of the sums of squared error from each model). Model III suggests that certain random factors (perhaps events in the macroeconomy) may affect all units and that taking into account this similarity will improve the estimates of the individual response coefficients. This model may be taken as the alternative hypothesis and compared to model I, again using an F test. Model IV implies differences in both level (intercept) and response (slope) coefficients across units, with no relation through the error terms.

If one of II, III, or IV represent the true model, then application of model I to the data will result in biased estimates of the response coefficients. The direction and magnitude of the bias will often be difficult to determine \textit{a priori}. Models II, III, and IV account for the existence of various differences among response coefficients by region through the use of binary variables. In general, in each region a binary variable is defined to be one for observations on that region and zero for observations on all other regions. A more detailed description of this technique is given in standard statistical and econometric texts (see, for example, Johnston (1984)).

This procedure may be applied to sensible aggregates of data containing more than one CRD. To determine candidates for grouping, CRD boundaries may be compared to soil map delineations. Regions with similar soils and topography may exhibit fairly homogenous yield response to changes in weather and technology. This approach can be useful in building aggregates because it provides a statistical basis for determining appropriate groupings. Huff and Neill's (1982) aggregation scheme was similar although apparently it did not allow for aggregation of CRD's across state boundaries and did not draw on soil similarities. Moreover, it had no systematic framework for judging the validity of the resultant groupings.

To isolate the effect of changes in technology and weather on crop yields in a particular region, an empirical study should control for differences in yields among regions which are not directly attributable to changes in technology and weather. Estimates of response coefficients may be biased if such control is not incorporated in the estimation design. Since the response coefficients are ultimately of interest in considering the impact of weather modification, high quality estimates are desirable. Approaching the problem in the framework of hypothesis testing will help avoid imposing untenable assumptions on the data that may ultimately bias the results.

6. MEASURING THE "WEATHER EFFECT"

Recently, Sonka (1979), reviewing the available literature on the economic impacts of planned weather modification, noted a rather large number of studies which document relations between rainfall and economic activity in the agricultural sector. These studies differ in their locational focus, crops considered, approaches used to measure potential gains, and linkages to national markets. Several studies are notable for their efforts to model the impact of augmenting summertime precipitation.

Huff and Changnon (1972) considered the benefits from average increases in rainfall and the uncertainty associated with precipitation modification. Crop yield and weather data for a 30-year period were used to develop relations between yields of the two major Illinois crops (corn and soybeans) and technology, temperature, and precipitation. Results indicated successful modification would be beneficial in most growing seasons.

Several studies (South Dakota State University, 1972; Kansas Agricultural Experiment Station, 1978; Cooter, 1984) have considered the effects of increased rainfall on state economies. Effects of additional precipitation on agriculture were evaluated using input-output multipliers. Results varied with assumptions regarding timing of rainfall and differing price effects. In general, increased precipitation raised income rather substantially.

At the national level the impact of increased precipitation was assessed in a study of hail suppression (Changnon et al., 1977). Using programming techniques, the study found that the major impact of rainfall increases of 8 and 16 percent was
a slight reduction in production costs for food commodities. The major benefits accrued to landowners in adoption areas.

In general, research in this area is site specific (e.g. state units or smaller), views the impacts of weather modification strictly within a cross-sectional framework, and does not directly link national markets for commodities or their end-products to value determination.

7. PROPOSED METHODOLOGY

The methodology proposed here addresses several of these issues through a modeling effort which links consumption and production. This approach permits an effective assessment of the temporal impacts of weather modification, and classification of the interactions that exist between changing weather, production, prices and the value of the commodity.

An econometric model, developed to examine the livestock and feedgrain sectors of U.S. agriculture, assumes that the value of additional production depends on the interaction of supply and demand. Specific variables are included to analyze the influence of climate-related factors on feed production, range productivity and livestock numbers. Prices at various stages of the marketing system, determined by the interaction of supply and demand, then feed back into the production and marketing sectors of the industries and are reflected in subsequent production decisions.

The feed-livestock industries consist of a complex set of relations that involve biological and economic time lags, differences in the location of production, and changes in product characteristics. The supply and demand for feedgrains interact to establish their price. Similarly, the supply of livestock and the retail demand for meat determine prices of livestock and meat. The relations between output prices (livestock prices) and input prices (feedgrain prices) for the producer constitute the link between the two sectors influencing feedgrain and livestock production and consumption.

The econometric model explains the production and prices of corn and livestock, as well as consumption of U.S. corn domestically and in the export market. Specifically, the livestock and corn markets are linked through derived demand relationships. The model is annual in period, except for the hog production sector, which is semiannual and is estimated over 1961-62 to 1982-83. Beef cattle, hog, and broiler production are described in a series of recursive equations. Current livestock product prices are determined by the demand at the wholesale level. The feed demand for corn is derived from current livestock production levels. The demand for corn on the world market is composed of demand estimates for groups of importers, aggregated according to similarity of their import behavior. The U.S. is assumed to be the only world market supplier in which significant consumption/production adjustment to changes in world conditions are possible; corn exports by other countries are exogenous. The aggregate U.S. supply of corn is assumed to be the summation of the production from each crop reporting district. Equilibrium corn price is determined endogenously when the market clears and so demand and supply are equal.

The basic empirical model is dynamic, nonlinear (in variables) and contains 53 equations, of which 35 are behavioral equations and 18 are identities. Four aggregated equations explain domestic U.S. corn production, area harvested; yield; and an identity for production, (i.e., area harvested times yield; and an identity for production, (i.e., area harvested times yield). These four equations are to be estimated for each year, 1951-82, for each crop reporting district for the 9 major corn producing states, thereby adding 36 equations to the basic specification. Corn produced outside the major states will be modeled at the aggregated level.

8. BENEFITS OF WEATHER MODIFICATION

The nature of the model permits an assessment of the gains to the producers and indirectly to consumers. Successful weather modification is, in effect, an output-increasing technology. Crop production is performed in an economic environment which approximates a perfectly competitive industry. At the aggregate level, therefore, increases in output because of successful weather modification can result in a lowering of the market price for the commodity produced. Given that demand for agricultural sector output is largely unresponsive to price changes, this results in a reduction of total revenue to feedgrain producers.

This analysis assumes that weather modification techniques are effective in all producing regions and will be adopted uniformly. In all likelihood this is not true, especially where international production is involved. Probably, a more reasonable assumption is that crop producers can be divided into at least two categories: those in areas where weather modification is successful; and those in areas without weather modification. The economic impacts on the crop producer will differ between the two categories.

The individual producer in a region with weather modification has more output to sell, but since the price received is determined by aggregate market conditions, it is slightly lower.
than if the weather modification does not exist. More specifically, under fairly robust assumptions, in the area with successful weather modification production will reduce price less than the reduction in per unit costs (Edwards and Freebairn, 1984). The larger the percent of the crop influenced by the weather modification, the greater the decline in price. Thus, within the context of this study, farmers in a localized producing area, e.g. a crop reporting district, region or even a state, should gain from the introduction of weather modification in their area.

Producers in a region without weather modification also face the somewhat lower price. With no additional output increase from effective weather modification, these producers are worse off from development of an effective weather modification technology. Consumers of the final products (i.e., meats and derivatives of corn) will be better off because of the resulting lower prices. In terms of the market, this benefit can be measured as a reduction in expenditures at the wholesale level of the meat product sector.

The system's relations can be influenced by economic, governmental, technological, and weather related phenomena. Linking the corn supply response sector to the demand for corn permits a dynamic assessment of the benefits of successful weather modification, ceteris paribus. Simulation of alternative weather modification scenarios provides estimates of the impact of additional corn production on feed prices, corn consumption, livestock production, and prices. Specifically, the effects of each weather scenario can be found by calculating the changes in revenues accruing to producers and consumers in wholesale expenditures for meat between a base simulation (with "normal" weather) and simulations with modified weather.

9. CONCLUDING REMARKS

The methodology detailed in this paper is attractive for several reasons. It permits a dynamic assessment of alternative weather modification scenarios in an economic environment which approximates market conditions. Implicit in this formulation is that the value of weather modification is determined by market generated price. These prices, then, feed back into the production sectors for grains and livestock, thereby influencing subsequent production decisions.

Another interesting feature of the model is its ability to examine weather modification at a relatively disaggregated level of production. Crop reporting districts provide rather weather-uniform or homogeneous production areas. Monthly information on precipitation and temperature has been shown to be highly related to crop yield variability. Finally, the model permits a detailing of benefits to consumers and to producers in areas with and without successful weather modification programs.

Clearly, the proposed framework can be expanded to develop a more comprehensive assessment of weather phenomena. Meaningful extensions might include: 1) alternative crops effects; 2) impacts on other sectors of the economy and; 3) a more comprehensive detailing of weather phenomena. Several of these modifications could be incorporated into the proposed framework following procedures detailed previously in this study (e.g. Cooter, 1984). Following the spirit of this research, a more complete incorporation of the impact of weather phenomena on alternative crops (e.g., soybeans) would lead to the development of an interactive econometric representation of the commodi ties affected.

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10. REFERENCES


and


