Weather

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A STUDY OF THE INTERACTION OF WEATHER WITH ALTERNATIVE ENVIRONMENTAL POLICIES

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Montana State University, Bozeman

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Abstract

This study is undertaken to evaluate the relationship between various agricultural environmental policies and weather variations. The indices for relative weather variability in each state are estimated by grafted polynomials and are incorporated into the changes in production patterns under alternative environmental policies to evaluate the impacts of the policies on the variability in production due to weather.

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Environmental concerns and technological changes are closely interrelated factors in agricultural production. Technical innovations in the form of improved farming practices and new and more intensive applications of chemical inputs have resulted in an upward trend in per acre grain yields. However, the increased usage of chemical inputs such as fertilizers, insecticides, and herbicides may also be a significant source of pollution. Other environmental concerns such as soil loss and the disposal of livestock wastes affect agricultural production capacities and may degrade soil and water quality. In addition, weather variability causes signficiant year-to-year fluctuations in grain production around trend levels and is one of the most important sources of uncertainty in future grain supplies.

Most environmental factors other than weather can be controlled within limits by the application of appropriate management and farming techniques. Weather, on the other hand, is for the most part uncontrolable. Other than in limited areas of irrigation, a farmer is primarily dependent upon nature to determine the growing conditions his crop will experience. General weather conditions and the degree of variability in weather from year-to-year are quite different from region to region within the United States. Thus, environmental policies that change regional production patterns also change the expected variability in agricultural production due to weather conditions.

Objective

This study, given the complex interrelationships between the environment, technology, and U.S. agriculture, is undertaken to evaluate the relationship betwwen various environmental policies and the corresponding weather-induced variation in grain production. Alternatives that will be analyzed include a restriction on soil erosion, a restriction on nitrogen fertilizer usage, a livestock waste runoff control restriction, a limited restriction on organochlorine insecticides, and a measure of the effect of all of these environmental restrictions on the overall U.S. production capacity. Each alternative is analyzed to determine if the resultant changes in regional production patterns cause an increase or decrease in the expected variation in U.S. grain production due to weather.

Statistical Estimation of Weather Effect

Per acre grain yields depend upon technology, weather conditions, prices of all chemical inputs, lagged grain prices, and acreage engaged in production. A quantitative measurement of weather conditions throughout the year is complicated and does not represent the real impact of weather on grain production because of seasonal weather variability. Consequently, weather effects in grain production can be defined as the residual of regression equation where per acre yields are expressed as a function of the prices of all chemical inputs, lagged grain prices, acreage, and technology. However, all independent variables except a time trend, representing technology are statistically insignificant in estimating grain yields. Thus, grain yields per acre can be expressed simply as a function of a time trend. Technical innovations in farming practices and new and more intensive use of chemical inputs and hybrid seeds are primarily responsible for the upward trend in per acre yields. Deviations from the trend level represent the effects of all other factors including weather, prices of all chemical inputs, and grain prices. However, the deviation from the trend level are the result primarily of weather variations because of the insignificance of the price variables in the yield estimation. In addition, the effects of price variables included in the weather effect are cancelled out in the process of calculating the index of relative weather variability in grain production in each state.

Actual yields from the period 1921 through 1974 were used in estimating the regression equations. A major shift in grain production occurred between 1954 and 1958; before this period, trend yields were increasing at a positive but rather slow rate and after this period, trend yields have been increasing much more rapidly. The major shift in the yield trend can be attributed to rapid adoption of technological improvements such as hybrid varieties, increased usage of chemical inputs, and usage of larger machinery complements. Therefore, the technology and weather effects are calculated by using the following grafted polynomials (4).

Two yield equations can be defined for each crop as follows:

(1) $Y_{it}^{S} = \alpha_0 + \beta_0 t + u_i \quad t \leq t^*$

(2) $Y_{it}^{S} = \alpha_1 + \beta_1 t + v_i \quad t > t^*$

where Y_{it}^{S} and t represent yield of crop i in time t in region S and time trend variable respectively. t* indicates a particular year between 1954 and 1958 depending upon the region. And u_i and v_i represent disturbance terms reflecting primarily weather variations.

Since equations (1) and (2) are continuous at time t*, the following equality can be obtained from equations (1) and (2).

$$(3)\quad \alpha_0 + \beta_0 t^* = \alpha_1 + \beta_1 t^*$$

Also equation (4) can be derived from equation (3).

$$(4)\quad \alpha_1 = \alpha_0 + (\beta_0 - \beta_1)t^*$$

Substituting equation (4) into equation (2) and, adding and subtracting β_{it} yields equation (5).

$$(5)\quad Y_{it}^S = \alpha_0 + \beta_0 t + (\beta_1 - \beta_0)Z_{it} + v_t$$

where $Z_{it} = 0$ if $t \leq t^*$, and $Z_{it} = t - t^*$ if $t > t^*$.

Equation (5) represents technical trend in grain production and deviations from this trend show weather effects in grain production. Empirical estimation of grain yields are shown in Table 1. Both independent variables, t and Z appears significantly in the grafted polynomials for all grains except soybeans. Soybean yields have smooth upward trends through the years rather than kinked trend at t*.

Since we defined weather effects as the deviations from the regression trend esitmated by grafted polynomials and technology effect as the regression trend. Average weather and technology effects on grain yields are calculated using the following equations:

$$(6)\quad \text{Average Technology Effect } (T_i^S) = \frac{\sum_{i=1}^{n} Y_i^S}{\sum_{i=1}^{n} Y_i^S} \times 100$$

$$(7)\quad \text{Average Weather Effect } (W_i^S) = \frac{\sum_{i=1}^{n} |e_i^S|}{\sum_{i=1}^{n} Y_i^S} \times 100$$

Table 1

Estimated regression coefficients of grafted polynomials

	Constant	t	Z	R^2
(1) Wheat	6.727	0.2371 (8.177)[a]	0.4521 (5.625)	0.8899
(2) Corn	2.787	0.7501 (9.441)	1.855 (8.420)	0.9310
(3) Oats	18.90	0.3248 (6.014)	0.5713 (3.816)	0.8042
(4) Barley	13.69	0.2675 (6.592)	0.6408 (5.679)	0.8639
(5) Sorghum	0.9832	0.4361 (5.586)	1.505 (6.954)	0.8693
(6) Soybeans	5.319	0.3011 (22.62)		0.9061

[a] Values in parentheses are t values associated with independent variables in statistical model.

where Y_i^S = actual yield of crop i in region S, Y_i^S = estimated yield of crop i in region S, and e_i^S = residual of crop i in region S.

Table 2 shows the weather and technology effects for several grains in the United States. During the period 1921-1974, approximately 87 percent of U.S. average wheat yield was attributed to changes in technology and 13 percent of yield attributed to weather fluctuations. This compares to an average over all grains of 89 percent attributed to changes in technology and the remaining 11 percent as a result of weather variations. The individual weather effects differ among grains as the location of production of these grains differ. Much of the U.S. wheat crop is produced in the

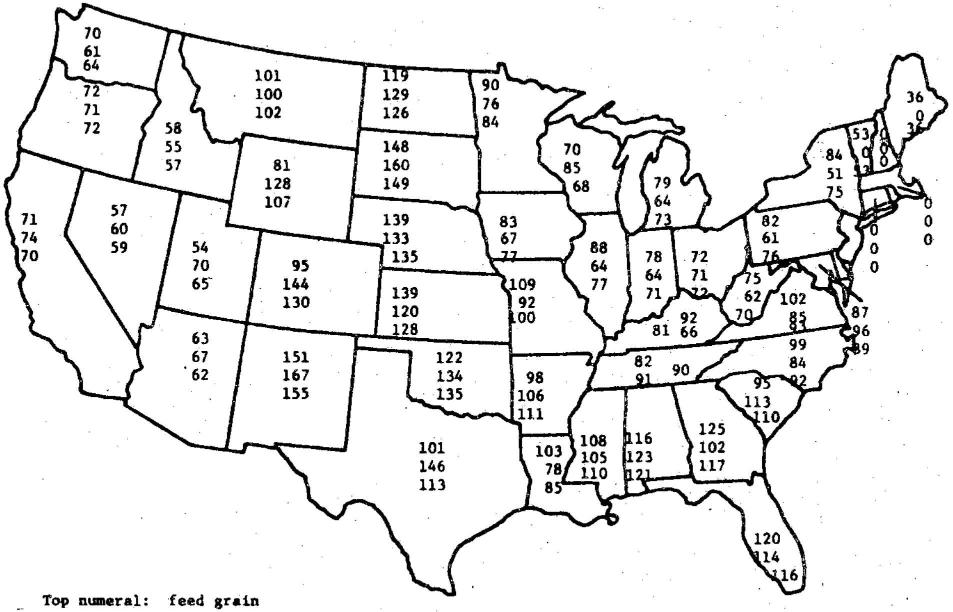
Great Plains where weather fluctuations are more severe than the U.S. average; thus, wheat yields are quite variable. On the other hand, corn yields are relatively less variable since the majority of corn production is located in states where weather variations are less severe than average U.S. weather variations.

Table 2

Estimated percentages of grain yield variations attributed to changes in technology and weather, 1921-1974

	Technology	Weather	Total
Wheat	87.15	12.85	100
Corn	90.45	9.55	100
Oats	88.85	11.15	100
Barley	90.20	9.80	100
Sorghum	88.03	11.97	100
Soybeans	90.74	9.26	100
Average	89.31	10.69	100

Weather and technology effects are estimated for each of the 48 continental states. Indices of relative weather variability for each grain in each state are calculated in order to determine the relative significance of weather in grain yields. The indices are calculated by dividing the weather effect for each grain in each state by a weighted average weather effect over regions and grains. Hence, a weather index value of 100 indicates that the variation of weather in that state is the same as average national variation. A weather index value greater than 100 indicates that the variation of weather is greater than the average variations and a weather index less than 100 indicates that the variation



Top numeral: feed grain
Middle numeral: food grain
Bottom numeral: all grains

Figure 1. Estimated weather index by state

is less than average. These weather indices are aggregated into feed grains, food grains and all grains for each state and reported in Figure 1.

Interaction Between Environmental Policies, Export Levels and Weather Variability

Significant interrelationships exist between environmental restrictions, export capacity, and weather-induced variability in grain production. Alternative environmental and export policies result in varying regional production patterns. By incorporating these changes in regional production with the regional weather indexes detailed in the previous section, the impacts of the environmental or export alternatives can be quantified. The formula used to estimate the impact of alternative environmental and export policies on the expected variability in production due to weather is as follows:

$$(8) \qquad WI_J^E = \frac{\dfrac{\sum_{i=1}^{48} W_{ij} \cdot P_{ij}^E}{\sum_{i=1}^{48} P_{ij}^E}}{\dfrac{\sum_{i=1}^{48} W_{ij} \cdot P_{ij}^B}{\sum_{i=1}^{48} P_{ij}^B}}$$

where

WI_j^E = relative change in weather variation under the Eth environmental policy in the production of the jth grain;

W_{ij} = weather effect in the ith state in the production of the jth grain;

P_{ij}^E = quantity of the jth grain produced in the ith state under the Eth environmental policy; and

P^B_{ij} = quantity of the jth grain produced in the ith state without any environmental constraints.

WI^E_j can be interpreted as an environmental index of weather. An index value of 100 indicates that implementation of the environmental policy does not affect the expected weather variability in grain production. A value greater than 100 indicates an increase in the expected variability in production due to weather and a value less than 100 a decrease in the expected variability due to weather. Regional grain production under each environmental alternative is obtained from a study done by Vocke (28).

The linear programming model used in this study is summarized below. For a more complete description see Vocke (18).

> The model has 105 producing areas, 28 consuming regions, and 12 major zones. Land resources are separated into 5 soil classes based on productivity and erosion characteristics. In addition to the crop sector, the model includes endogenous livestock and transportation sectors. Major constraints include the availability of land resources by the five soil classes, water resources in the 17 western states, and the regional demands including exports of the major crop and livestock commodities. The model minimizes the total cost of producing and transporting the commodities to meet the regional demands given the available land and water resources, and subject to restrictions imposed by the particular environmental alternative.
>
> Regional production patterns were determined for the following alternatives: (1) a maximum per acre soil loss equal to the soil tolerance level,[1] (2) livestock feedlot runoff controls similar to E.P.A. guidelines, (3) limiting the application of commercial nitrogen fertilizer to 50 pounds per acre, (4) withdrawal of the chlorinated hydrocarbons aldrin, dieldrin, chlordane, and heptachlor from use on corn, (5) production capacity with no environmental restrictions, and (6) production capacity with a combination of policies 1 through 4.

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[1] The soil loss tolerance level is defined as the maximum rate of soil erosion that will permit a high level of crop productivity to be sustained economically and indefinitely (19).

Table 3 indicates the relative impact of the various policies on the expected variation in grain production. The change in variability is the result of different regional production patterns under alternative environmental policies. The variability in feed grain production increases more than that in food grain production for all environmental alternatives. The reasons behind these results are best illustrated by the general shifts out of the Corn Belt and Lake States into the Great Plains and occasionally into the Southeast and Delta States. Sorghum shifts out of the Delta States into the Great Plains and Corn Belt. Barley and oats reactions are mixed depending upon the policy. The primary source of increased variability in feed grain production is the general shift in corn production from regions of relatively stable weather to regions with greater weather variability.

Table 3

Estimated relative increase in weather variations of grain production under the various policies

Policy		Feed Grain[a]	Food Grain[b]	All Grains
I.	Base	100.00	100.00	100.00
II.	Soil Loss	104.04	100.09	102.41
III.	Livestock	100.03	100.00	100.01
IV.	Nitrogen	101.34	100.19	101.33
V.	Insecticide	100.18	100.07	100.28
VI.	High Export	102.39	101.84	102.79
VII.	Combination	104.54	100.68	102.99

[a] Feed grain includes corn, barley, sorghum and oats.

[b] Food grain includes wheat and soybeans.

Wheat production shifts out of the Great Plains to the Corn Belt, Lake States, and occasionally the Delta States under the environmental alternatives. This shift is from areas of relatively high to areas of relatively low variability. Soybeans, on the other hand, shift out of relatively low weather variability areas into the Great Plains with the net effect of an increase in expected variability. As a result of the two counterbalancing forces, the overall change in variability in food grain production is insignificant.

Another general result is that the overall impact of an alternative on the expected weather variability in production is positively correlated with the "severity" of the alternative. The combination high export and environmental restrictions results in 4.54 percent increase in weather variability. Similarly, soil loss alternatives and the high export which rank second and third, respectively, in terms of increased weather variability, carry the same ranking with regard to severity of impact. The substantial increase in demand under the high export alternative and the general reduction in available rotations in erosive areas under the soil loss alternative are the two most important single factors with regard to changing the regional distribution of production. The more moderate nitrogen alternative ranks fourth followed by the insecticide and livestock runoff alternatives.

Conclusion

Alternative environmental policies change the regional patterns of grain production in the United States and consequently, cause greater fluctuations in grain production. As the alternatives become more restrictive, the expected weather induced variability increases. Variability in feed grain production increases more than that in food grain production for all environmental alternatives. This result does not recognize that alternatives such as our soil-tolerance level of allowable per acre soil loss, which help maintain the productive capacity of our natural resource, may in the long run decrease weather-related variablity.

The increase in expected variability at least in the short run as the result of implementation of an environmental policy increases uncertainty in future supplies and may thus require a counterbalancing storage policy to offset the increased fluctuation in supply. Therefore, evaluation of each policy should be based on an analysis of the benefits, costs, and interactions of both policies.

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