Impact of Weather and Technology on Net Return Estimates

By E. L. Michalson

STUDENTS OF AGRICULTURAL economics have observed that many budgetary linear programming and other econometric models tend to overestimate crop production. This overestimation of crop production subsequently leads to very optimistic estimates of net returns for optimum farm organizations developed from such models. The cause of this overestimation of production results from the practice of using average or representative crop yield coefficients which are not weighted to eliminate the effects of weather and technology. Such yield coefficients are usually normative and often are determined independently of their relationships to other crops. The use of this type of crop yield coefficient tends to create an upward bias in estimated production because it abstracts from the normal variability inherent in crop yields. Day reported that his work on regional production dynamics tended to overpredict field crop yields (1, p. 713-741).[1] He demonstrated that the asymmetry of the crop yield probability function is an important cause of this imprecise prediction. Skewness was only part of the problem. An interaction existed between the shape of the yield probability function and the amount of nitrogen fertilizer applied to the crop. Day concluded that an econometric model of a single firm or a small relatively homogeneous area that used average yields at high nutrient levels would overpredict yields more often than underpredict them.

The results of this study tend to support Day's conclusion. Under the cropping conditions observed in the study area, average yields tended to overestimate production compared with yields weighted to eliminate the effects of weather and technology.

In this analysis it is assumed that the effects of weather and technology on crop yields are temporal with considerable variation occurring from year to year. It is also assumed that the combined effects of weather and technology on crop yields are interrelated, and that these effects are independent of managerial control.

Weather is defined as all those environmental forces influencing crop production which are beyond the control of the farm manager (4, p. 3). These forces include rainfall, temperature, and other influences such as crop diseases and insect infestations. Technology is defined as all those factors which have gone into developing higher crop yields. These factors include fertilizer, herbicides, and varietal improvement. In addition, all allocative decisions affecting resource use are assumed a priori, and no attempt is made to determine the effects of weather variation on resource allocation. Finally, this study does not attempt to explore price and quantity variance as they might be affected by weather.

The Study Area

The setting of this study is in the wheat-pea area of eastern Washington and northern Idaho. This area consisted of about 1,120,000 acres of cropland and 3,000 farms in 1964 (3, p. 2-3). The average farm size was 484 acres of which 377 acres were cropland. The wheat-pea area covers parts of Spokane and Whitman counties in Washington, and Latah, Nez Perce, and Lewis counties in Idaho.

Sources of Data

Crop yields, monthly temperatures, and rainfall data were obtained from records maintained at the Palouse Conservation Field Station located near Pullman, Wash.[2] The meteorological data consisted of hourly rainfall records and daily maximum and minimum temperatures for each month.

[1] Underscored numbers refer to Literature Cited, p. 22.

[2] G. M. Horner and L. C. Johnson maintained these records over 22 years.

A variable measuring the aggregate effects of technology was also used in the analysis. The aggregate technology variable was defined in terms of pounds of nitrogen, which permitted measuring its application in discrete units. This aggregate technological variable was derived by using a linear function developed by Legget (2, p. 11-15).[3] This formula indicated that about 3.0 pounds of nitrogen are required from all sources for each bushel of wheat grown. This functional relationship was used to determine the aggregate effect of technology on wheat yields because no records of fertilizer or pesticide use were available. The technological variable also reflects the effects of herbicides and varietal changes. Because of a lack of data, it was not possible to identify how much each individual item has contributed toward increasing yields. It was, however, possible to identify the dates of important technological changes in the wheat-pea area. These were: 1949, the introduction of fertilizer; 1956, the introduction of the Omar wheat variety; 1962, the introduction of Gaines wheat. Average yields increased from about 34 bushels to about 63 bushels per acre during this time.

Analytical Procedure

A multiple regression model was hypothesized using meteorological and technological variables to estimate crop yields. Originally both additive and multiplicative relationships among these variables were hypothesized, and both types of statistical models were tested. The additive model had a much higher R^2 and all of the β values were significant at the 0.01 level, which was not the case for the multiplicative model.

The additive model contained meteorological variables–June and July average daily temperatures, and seasonal rainfall–and the aggregate technology variable. Other variables hypothesized had been rejected on the basis of their lacking significant β values.

---

[3] The formula used was $Y = 11.8 + 0.348X$; where Y = bushels of wheat per acre, and X = points of soil nitrate and nitrogen fertilizer. This equation was solved for total pounds of nitrogen required to produce the yield reported for each year. The pounds of nitrogen available from natural sources were deducted and the remainder was assumed to be available from fertilizer, pesticides, and the increased vigor of new varieties. These data were then averaged over the time periods relevant to technological change and the resulting amount of nitrogen was used as an input for the aggregate technology variable. The average amount of nitrogen applied was 40 pounds per acre from 1949 to 1951, 60 pounds per acre from 1952 to 1956, 80 pounds per acre from 1956 to 1961, and 120 pounds per acre from 1962 to 1967.

Wheat was selected for the analysis because (a) it has benefited most from technological change, (b) adequate data were available, (c) it is the most important crop produced in the area, and (d) the effects of weather are relevant to specific crops (5, p. 4).

The model hypothesized for the study was:

$$Y = 276.450 - \underset{(0.641)}{2.062X_1} - \underset{(0.678)}{2.317X_2} + \underset{(0.394)}{1.539X_3} + \underset{(0.031)}{0.282X_4}$$

where Y = yield per acre,
X_1 = June average temperature,
X_2 = July average temperature,
X_3 = total rainfall, and
X_4 = technology.

The coefficient of determination and the standard error of estimate of the regression curve were $R^2 = 0.843$, and $S_{y.x_1.x_2.x_3.x_4} = 5.632$. The partial regression coefficients were all significant at the 0.01 level or greater, and all signs were logical. The standard errors of the betas are shown below the coefficients.

Yield Categories

The multiple regression equation hypothesized above was used to develop a yield probability distribution for wheat. To develop any probability distribution some class interval must be defined. This class interval is usually selected from an arbitrarily defined frequency distribution. In this analysis, the standard error of estimate of the estimated regression curve was used to define normal yield. This normal yield is a range of yields varying from the +1.0 to –1.0 standard errors around the regression curve.

The standard error of estimate calculated for the above multiple regression curve was 5.6 bushels per acre. A normal yield would be any yield falling within a range of +5.6 or –5.6 bushels per acre around the regression curve. If the estimated yield were 40 bushels per acre, then a normal yield would vary from 34.4 to 45.6 bushels per acre. This definition created three categories of yields: A, supernormal yields lying above one standard error ($P = 0.09$); B, normal yields lying within one standard error of the estimated yields ($P = 0.68$); and C, subnormal yields lying below one standard error ($P = 0.23$).

Crop Yield Indexes

Once the yield categories were defined, crop yield indexes were developed for each crop. The formula used to develop these indexes was:

$$I = (\Sigma Y/N)(1/X)$$

where I = the index for a category (A, B, or C),
Y = the summation of yields (in A, B, or C),
N = the number of observations in each category (A, B, or C), and
X = the weighted average yield for all categories.

A yield index was computed for each category using the yields observed in each category. These indexes were all based on the probability distribution developed above for wheat. This procedure related the crop yields of other crops in the rotation to those of wheat, and was used because all these crops are grown simultaneously in a rotation. If separate yield probabilities had been computed for each crop, the estimated net returns would not have been consistent with the yield levels resulting under a specific set of weather and technological conditions. In other words, the optimum weather for maximum wheat yields is not necessarily that for maximum barley or dry pea yields.

Estimating Net Returns

The above yield indexes and probability distributions were used to compute a new set of gross returns estimates for a set of farm organizations developed using linear programming (3, p. 18). The basic cost structure of these firms, developed in the linear programming analysis, is maintained and net returns are estimated for each crop yield category. Then a simple expectation model is used to determine the expected value of net returns for each farm size.

The mathematical model used was:

$$\phi = \Sigma X_{ij}Z_j \ (i = 1, 2, 3)$$

where ϕ = weighted value of net returns,
X_{ij} = the expected net return for each yield outcome, and
Z_j = the probability of a yield outcome.

This mathematical expectation is the average net return expected over time.

Results

The net returns estimated using the regression results were compared with those developed by the linear programming analysis, and are shown in table 1. The net returns in the linear programming models varied from $1,228 for the 600-acre wheat-pea farm to $18,604 for the 1,900-acre farm. When the multiple regression data are used these returns vary from $629 to $16,904. The linear programming analysis overestimated net returns by 49 percent for the 600-acre farm, 17 percent for the 800-acre farm, 11 percent for the 1,200-acre farm, and 9 percent for the 1,600- and 1,900-acre farms. These differences are estimates of the bias resulting from using single-value yield coefficients, which represent average-yield response, compared with using those that reflect the impact of weather and technology on crop yields.

One interesting point that came out in this study is that errors in estimated net returns vary with farm size. As size is increased from 600 to 1,600 acres, the farm's fixed resource capacities are more fully utilized. This

Table 1: Net returns estimated using constant and variable crop yield coefficients

Item	Crop yield categories			Multiple regression model	Linear programming model	Percent (5) is of (6)
	A	B	C			
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Probability	.09	.68	.23	1.00	1.00	–
Farm size:	Dollars					
600 acres	3,816	702	-833	629	1,228	51.2
800 acres	8,046	3,984	1,903	3,871	4,645	83.3
1,200 acres	16,161	10,032	6,880	9,369	10,526	89.0
1,600 acres	24,054	15,929	11,765	15,702	17,253	91.0
1,900 acres	26,411	17,265	12,119	16,904	18,604	90.9

increased utilization tends to have a modifying effect on estimated net returns, which can be observed in column 7 of table 1. The percentage that net returns are overestimated declines as size increases. This upward bias of net returns declined from 49 percent to 9 percent from the smallest to the largest farm sizes. This result implies that larger farms may be more able to withstand the vagaries of weather.

This analysis provides a more realistic estimate of net returns than linear programming or budgeting, because it eliminates the variation introduced by weather and technology from the determination of normal yields. This permits a direct evaluation of the bias introduced into an analysis by using average-yield coefficients to estimate crop production. The advantages of this procedure are that it requires only a minor amount of additional data, and that it can be used in almost any kind of study which relies on budgetary or programming techniques.

Literature Cited

(1) Day, R. H. Probability distribution of field crop yields. Jour. Farm Econ., Vol. 47, No. 3, p. 713-741, Aug. 1965.

(2) Legget, G. E. Relationships between wheat yield, available moisture, and available nitrogen. Wash. Agr. Expt. Sta. Bul. 609, Dec. 1959.

(3) Michalson, E. L. Economics of farm size in the Washington-Idaho wheat-pea area. Wash. Agr. Res. Center, Tech. Bul. 52 (in process).

(4) Shaw, L. H., and D. D. Durost. The effects of weather and technology on corn yields in the Corn Belt, 1929-62. U.S. Dept. Agr., Agr. Econ. Rpt. 80, July 1965.

(5) Shaw, L. H., and D. D. Durost. Measuring the effects of weather on agricultural output; procedures for constructing weather indexes. U.S. Dept. Agr., ERS-72, Oct. 1962.