A STOCHASTIC MODEL OF DISASTER PAYMENTS UNDER THE 1973 FARM ACT

By Thomas A. Miller and Ronald H. Millar*

A stochastic computer simulation model is used to estimate disaster payments under the Agriculture and Consumer Protection Act of 1973. The model uses a random yield generator and actuarial techniques. Simulated payments under 1976 program parameters and stochastic yields are estimated at $300 million, compared with actual payments of $522 million in 1974 and $262 million in 1975. A payment greater than $522 million will probably not occur again under current conditions. The $262 million level is closer to normal expectations. The model also evaluates the impact of revisions in the payment program, as well as the effect of uncertain crop yields.

Keywords: Disaster Payment Program, disaster payments, crop insurance, risk, agricultural and food policy.

A stochastic simulation model was developed to aid research on Government protection of producers from income losses when crops are damaged by natural disasters (*5*, *6*, *7*).[1] Estimates of future Government costs of the various disaster program options are important for program development and administration. In this article, we review the Disaster Payment Program (DPP) of the Agriculture and Consumer Protection Act of 1973, describe the structure and application of the simulation model, and provide estimates of expected costs of the current DPP under possible conditions in 1976.

THE DISASTER PAYMENT PROGRAM

Under the Disaster Payment Program, farmers can be reimbursed for some of the income lost because of crop failures. The program, administered by USDA's Agricultural Stabilization and Conservation Service (ASCS), covers corn, grain sorghum, barley, wheat, and upland cotton (*1*, *2*).[2] The act of 1973 states:

> If the Secretary determines that, because of such a disaster or condition, the total quantity of wheat (or other nonconserving crop planted instead of wheat) which producers are able to harvest on any farm is less than 66-2/3 percent of the farm acreage allotment times the projected yield of wheat (or other nonconserving crop planted instead of wheat) for the farm, the rate of payment for the deficiency in production below 100 percent shall be . . . one-third of the established price.

Similar provisions exist for feed grains and cotton, and a payment is made if a producer is prevented from planting a program crop on his allotment acreage. However, we consider only the low yield portion of the DPP.

Under the DPP, producers who plant within their allotments are eligible for payment when their actual yield is less than their disaster yield (defined by ASCS as two-thirds of their historical yield). Producers who plant in excess of their allotment must have a substantially lower actual yield to be eligible, since production from total acreage is counted in determining eligibility for payment on the allotment acreage. A number of questions have been raised concerning how ASCS defines the disaster yield (*9*) and how basing the program on existing allotments reduces or denies coverage to producers who overplant (*5*, *6*, *9*). However, such questions are beyond the scope of this analysis, except in the sense that the simulation model provides the capability for evaluating modifications in the legislation.

Treasury costs under the DPP can vary greatly from year to year, depending primarily on crop yields. The model helps to ascertain whether payments, such as the $522 million in 1974 and $262 million in 1975, represent typical costs of the program, or whether they are extremes not likely to be repeated. Uncertainty concerning the expected costs of the DPP has led to difficulties in the budgeting process, as well as misgivings concerning the program's appropriateness as a vehicle to ameliorate farmers' uncertainty. Policymakers need estimates of future payments under the disaster provisions of the 1973 act to (a) improve the budgeting process, (b) evaluate the effectiveness of the current legislation, and (c) evaluate proposed modifications of the current legislation.

MODEL STRUCTURE AND PROCEDURE

The stochastic computer simulation model generates a sample of expected crop yields, and computes payments for each of them using insurance actuarial methods and the parameters of the particular disaster payment program being evaluated. Lastly, the model accumulates results in the form of probability distributions of the expected payments.

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[1] Italicized numbers in parentheses refer to items in References at the end of this article.

[2] The program was later extended to rice with passage of the Rice Production Act of 1975.

The Required Parameters

The computer program uses two types of data—the specific parameters of the DPP provisions being analyzed and the parameters of the yield distributions. DPP parameters shown in table 1 include the disaster yield, the established yield (determined by ASCS), the payment rate, and the allotment or base acreage for each of the five program crops. Tables 2 and 3 show the crop yield parameters required by the model—the trend and expected value of future crop yields, the variance around this trend, the correlations between the yields of the different crops, and the standard deviations of all producer yields over space within the crop year being considered. The specific procedures used in estimating DPP costs and crop yield parameters will be described later after the general characteristics of the random yield generator, payment computation procedures, and model results are discussed.

Table 1.—Parameters for the 1976 Disaster Payment Program

Crop	Disaster yield	Established yield	Payment rate	Allotment or base
	Bushels		*Dollars*	*Million acres*
Corn	53.565	89.0	0.520	[1] 61.055
Grain sorghum	35.600	58.0	.500	[1] 16.137
Barley	28.057	44.4	.430	[1] 11.808
Wheat	19.897	32.6	.760	61.600
Cotton	[2] 310.800	[2] 551.0	.144	11.000

[1] See text for computation of feed grain base. [2] Cotton yield shown in pounds.

The Random Yield Generator

A hypothetical sample of yields is drawn from the yield population by use of a random number generator. A multivariate normal distribution of yields is assumed for the five crops. The assumption that yields follow a multivariate normal distribution over time is not unrealistic for this purpose at the U.S. level, although for smaller geographic areas, the distribution sometimes becomes noticeably skewed. Yields in one year are assumed independent from yields in the previous year. While this assumption may not be realistic, it does not affect the average distribution of disaster payments.[3]

Payment Computation Procedures

The disaster payment for each crop is computed as a function of the fixed DPP parameters and the randomly chosen U.S. average yield, considering each sampled observation as if it were a year. The conceptual linkage between national average yields and the amount of the disaster payment comes from crop insurance actuarial methods. The procedure resembles one used earlier by the Federal Crop Insurance Corporation in estimating annual loss-costs for setting all-risk crop insurance premiums (*8*, Ch. 18). For a given year and crop with an average U.S. yield, the actual yields of all producers are assumed normally distributed with a specific standard deviation. This standard deviation reflects the variation of yields with respect to space, not time. In figure 1, Y_i represents the average U.S. yield for the crop. The

[3] Of course if there were correlation among years, the level of payments in one year would be affected, given the yields of the previous year. Both the independence and skewness properties of U.S. crop yields are evaluated by Luttrell and Gilbert (*4*). However, their conclusions do not apply directly to the yield distributions used in this article, since their analysis is based on yields per harvested acre while the disaster payment question involves yields per planted acre.

Table 2.—Estimated 1976 yield parameters for the simulation model

Crop	Expected yield	Variance-covariance matrix				
		Corn	Grain sorghum	Barley	Wheat	Cotton
	Bushels					
Corn	85.650	80.100	34.324	13.959	7.627	103.045
			(.778)	(.487)	(.358)	(.291)
Grain sorghum	45.050		24.300	4.578	1.936	32.376
				(.290)	(.165)	(.166)
Barley	42.660			10.257	2.912	0.000
					(.382)	(.000)
Wheat	29.024				5.666	32.398
						(3.44)
	Pounds					
Cotton	433.900					1,565.436

Table 3.—Estimated variation of producer yields over space within a crop year

Crop	Standard deviation	Coefficient of variation
	Bushels	
Corn	17.609	20.2
Grain sorghum	5.709	11.5
Barley	5.914	13.9
Wheat	5.807	20.0
	Pounds	
Cotton	117.911	27.2

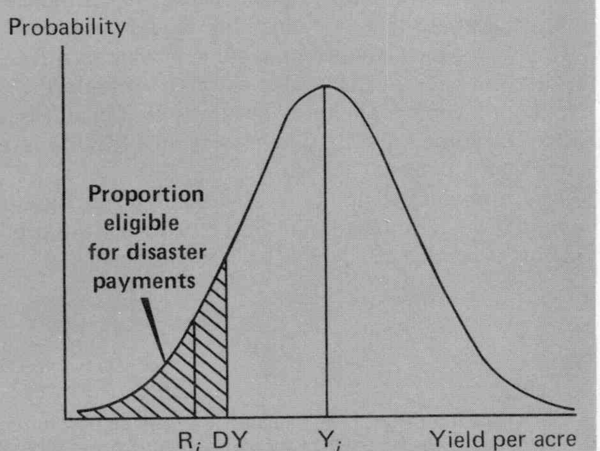
normal distribution serves as a proxy for the yields of all producers of that crop in that year.

Next we assume the DPP provides payments to all producers with yields lower than a specified, national average disaster yield (DY in figure 1). The proportion of producers that are eligible is represented by the hatched area to the left of DY. For all eligible producers, the average yield used in determining the total payment may be estimated as the average of all yields in the shaded portion, or R_i in figure 1. Since the standard deviation of this distribution of yields is fixed for a given year and crop, knowing Y_i enables computation of (a) the proportion of all producers that will be eligible for payment, and (b) the average yield of these producers.

Mathematically, the proportion of producers that are eligible is represented by the definite integral

FIGURE 1

Assumed distribution of all U.S. producer yields in one crop year



$$E_i = \int_0^{DY} f(x)dx \qquad (1)$$

where

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(x-Y_i)^2/2\sigma^2} \qquad (2)$$

with σ representing the standard deviation of producer yields over space within a year. The average yield of these producers (R_i in figure 1) is shown by

$$R_i = \frac{\int_0^{DY} xf(x)dx}{E_i} \qquad (3)$$

which represents the weighted average of all eligible producer yields under the normal curve from zero to DY.

The payment is computed as the product of (1) the difference between the yield of the eligible producers and the national ASCS-established yield, (2) the percentage of all eligible producers, (3) the payment rate, and (4) the allotment for the crop in question, or

$$P_i = (EY - R_i)\, E_i r L \qquad (4)$$

where

EY = the national average ASCS-established yield,
r = the payment rate per unit of production, and
L = the total allotment or base acreage of the crop.[4]

Tabulation of Results

The payment estimated for each crop in each sample observation is used to form the frequency distribution of payments over the entire sample. First, frequency distributions are tabulated for each crop, and the distribution of the total payment for all five crops is tabulated. Second after payments have been estimated for all sample observations, the program prints the mean values of the payments for each crop and for the total, and the frequency distributions for each crop and for the five-crop total. Also, the medians, quartiles, and percentile points can be determined from the frequency distributions as can the probability that payments will exceed a given level.

[4] This highly simplified procedure for estimating disaster payments contains numerous specification and aggregation errors. Implicitly it assumes that the average acreage of eligible producers equals the average acreage of all producers and that all producers plant within their allotment. However FCIC used a similar procedure with some success at the county level as mentioned earlier (*8*, Ch. 18). With the refinements discussed in a following section, the procedure was found to estimate aggregate disaster payments with reasonable accuracy.

APPLICATION AND REFINEMENTS OF MODEL

The Basic Data

Table 1 contains the estimated parameters for the 1976 DPP provisions. ASCS determines a disaster yield and an established yield for each county and farm participating in the program. (The established yield is sometimes called the projected yield, the program yield, or the farm payment yield.) The data in table 1 represent estimated 1976 national averages of the ASCS values. The disaster yields are estimated as two-thirds of the 10-year U.S. average yield per harvested acre for the respective crops. The established yields in table 1 are estimated on the basis of projecting the trend of historical established yields published by ASCS. The payment rates per unit of production and the national allotments or bases for the program crops for 1976 are also shown.

Since ASCS does not currently publish the base acreages for the individual feed grains, the total feed grain base for all crops has been allocated to corn, grain sorghum, and barley based on the proportions published by ASCS in 1973. All table 1 parameters were estimated before 1976 program statistics were available; thus, the data differ slightly from data later estimated by ASCS. However, the method used in computing the spatial standard deviations of table 3 provides a calibration procedure that corrects for these minor differences.

Table 2 presents crop yield parameters. While the DPP yield parameters are defined in terms of yields per harvested acre as required by the program, the parameters for the actual crop yields shown in table 2 are expressed in crop units per planted acre. These definitions correspond to the ASCS practice of determining DPP eligibility by comparing the actual production per planted acre (table 2) with the disaster yield (table 1). The expected values of yields are estimated using OLS regression and 1929-75 data. Linear time trends are segmented by dummy variables to reflect changes in the rate of increase. The wheat yield trend steepened in 1945, and that for barley in 1957, but cotton stabilized after 1963. The corn trend steepened sharply in 1956, and grain sorghum shifted upward in the same year; however both these crops lost most of the uptrend after 1970, along with a substantial increase in variance at that point, as recently discussed by Fox (*3*).[5]

The variance-covariance matrix is estimated from the residuals around the trend lines. The variance for wheat and barley remained constant over 1929-75; therefore, residuals for a 47-year period have been used to estimate variances. For cotton, the variance increased in the latter part of this yield history, and the 1957-75 residuals were used. For corn and grain sorghum, the higher 1970-75 variance is reflected in table 2. The values in parentheses below the covariances are the simple correlation coefficients represented by the respective covariances. It is important to include these relationships in the model since their existence makes a high payment for crop A likely in the same year that a high payment occurs for crop B, thus increasing the likelihood of a large total disaster payment.

The standard deviations of the distributions of individual producer yields over space denoted by σ in equation (2) are determined last. The only readily available method for estimating the necessary standard deviations is to equate them to the levels implied by the actual ASCS payment history for each crop in 1974 and 1975 (*1, 2*). Using 1974 and 1975 data, all of the variables and parameters of equations (1) through (4) can be known, except σ. The averages of the 1974 and 1975 standard deviations derived in this manner were used to estimate σ in the 1976 simulations, and they appear in table 3.

Estimating the required spatial standard deviations so that the model duplicates historical data has a special advantage—it provides a calibration procedure for the model that corrects it for many of the specification and aggregation problems described earlier. Such a calibration also enables the model to duplicate how the DPP is actually administered by ASCS, as opposed to how it may appear to operate in the abstract.

Model Refinements

The final simulation model was based on the concept of figure 1 with one additional refinement. The procedure described above was found to underestimate payments in situations where the disaster yield was less than 50 percent of the average yield. The combination of a very low disaster yield and a very high crop yield resulted in an eligibility estimate approaching zero for that year. However, experience of the crop insurance industry suggests that zero eligibility would not be expected under such conditions as some producers suffer losses even when overall yields are high. Therefore a minimum 2-percent eligibility level was used in all cases where the normal distribution showed an eligibility level lower than 2 percent.[6]

This minimum eligibility level necessitates revision of computation formulas. Equation (1) showing the proportion of producers eligible (E_i) now becomes

$$E_i = 0.02 + 0.96 \int_{A}^{DY} f(x)\, dx. \qquad (5)$$

[5] In computing a farm's production for disaster payment purposes, ASCS values a ton of silage as equivalent to 5.5 bushels of grain. This factor was used for all historical data in estimating the yield parameters. However, even with this silage equivalent included in the expected yields of table 2, they remain much lower than the ASCS-established yields of table 1, especially for grain sorghum and cotton. This discrepancy reflects how the DPP is defined and administered and does not represent an error in the model (see *9*).

[6] In a similar manner, FCIC established a "minimum annual loss-cost" to use in years when the normal curve procedure showed an unrealistically low loss-cost (*8*, p. 251).

The integral is scaled down by a factor of 0.96 to compensate for the added area. For these computations, the lower limit of integration, A, has been set at $Y_i - 2.96\sigma$, a level that reduces the computer cost of evaluating the integral and provides a smooth transition zone as eligibility increases from 0.02.

The average yield of eligible producers from equation (3) now must be modified as shown by

$$R_i = \frac{(A/2.0)0.02 + 0.96 \int_A^{DY} x f(x)dx}{E_i} \qquad (6)$$

which represents the weighted average of the yield for the minimum 2 percent eligible and the yield for the area under the normal curve from A to DY. When $A > DY$, $E_i = 0.02$ and $R_i = DY/2.0$, which represents the minimum payment level.

The payment computation procedure, refined to include the minimum 2-percent eligibility level, now uses equations (5), (6), and (4). Figure 2 depicts how the model computes a payment under low, medium, and high U.S. crop yields. The figure shows the disaster yield for the year in question, DY, and the established yield guaranteed to eligible farmers under the current disaster program, EY. For a year in which the yield is low (Y_1, Panel A), the hatched area represents eligibility E_1. The rectangular segment at the left of the frequency distribution represents the 0.02 minimum eligibility added to the normal curve. Medium and high yield situations appear in panels B and C, respectively (fig. 2). The total hatched area decreases as the U.S. yield increases—that is, the proportion of producers who qualify for disaster payments decreases as U.S. yields increase.

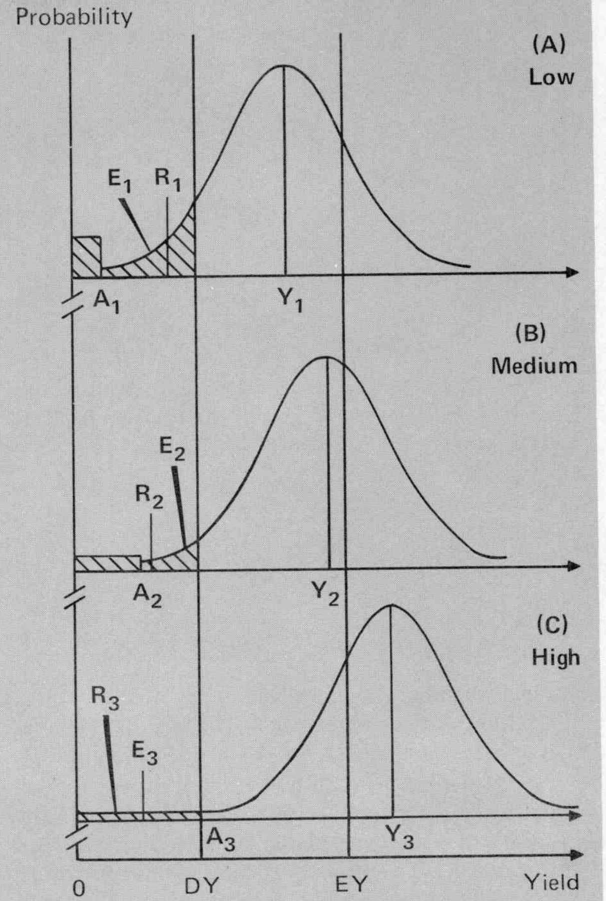
Note that the method shown in equation (6) to compute the average yield of eligible producers causes their yields (R_i) to decrease as average U.S. yields increase. This assumption is correct to the extent that two conditions exist. First, a relatively constant number of producers have a complete crop failure (zero yield) in each year. Second, decreases in U.S. average yields are related to an increase in the number of producers with yields close to the disaster yield level rather than an increase in the number of complete crop failures. This assumption represents the pessimistic view of the relationship between program eligibility, U.S. yields, and the yields of eligible producers. It is pessimistic in the sense that the estimated payment may be biased upward under the situation of a high U.S. yield and a low disaster yield. Therefore, computations using this model are less likely to underestimate total program costs.

ESTIMATED COSTS OF THE 1976 DPP

Given the model structure and parameters, the simulation model computes and tabulates the payments that would result if all cultural practices (fertilizer, planting rates, technology, etc.) and DPP parameters are held constant at the 1976 level and all random factors (weather, crop disease, and other natural hazards) are allowed to repeat 1,000 times. Figure 3 shows the expected distribution of payments computed under these assumptions. The expected value or average payment for the 1976 program is $300 million and the median payment is $267 million. As a basis for comparison, payments under the low yield portion of the 1974 DPP were $522 million, payments under the 1975 DPP were $262 million, and preliminary estimates for the 1976 DPP are $452 million.[7] These are actual payments for single years, compared with the 1,000 observations of expected payments data represented in figure 3.

A payment of less than $150 million would occur 5

FIGURE 2
Disaster payment computation procedure under three yield levels for U.S. crops



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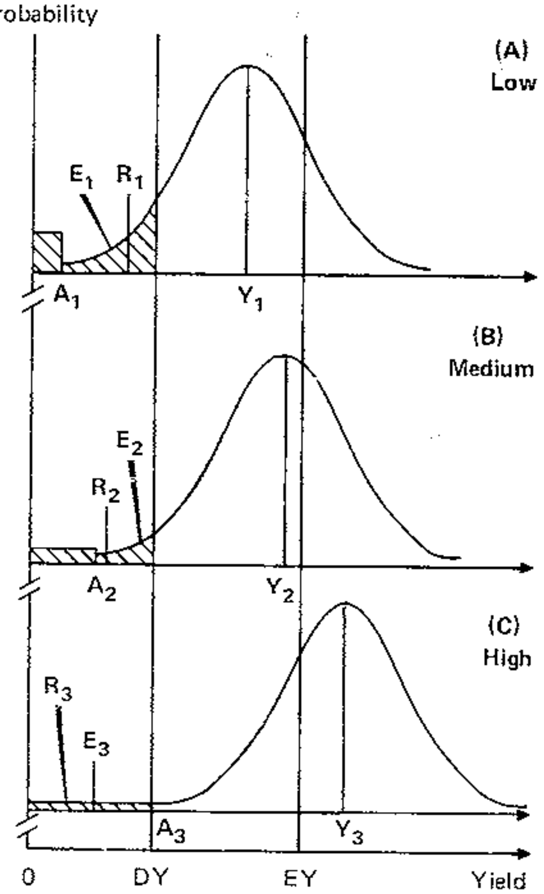

ESTIMATED COSTS OF THE 1976 DPP

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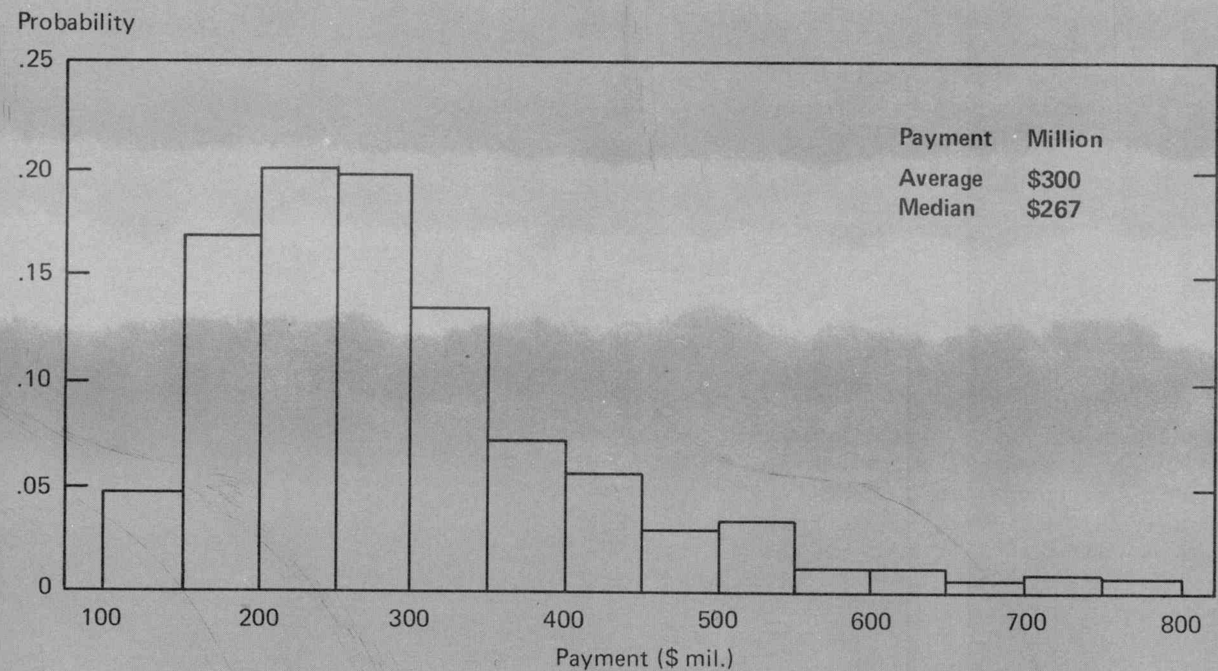
FIGURE 3
Expected low-yield payments under the current DPP, 1976



times in 100 and at the upper end, a payment of over $750 million would occur once in 100 (fig. 3). Thus the actual disaster payments in 1974 and 1976 were probably higher than what would be normally expected—the probability of a payment exceeding $522 million is only about 0.07 while the probability of exceeding $452 million is about 0.14. Because 1974 crop yields were much lower than expected, the likelihood of another disaster payment as large is small, given the same DPP parameters. Of the 3 years, the 1975 payment of $262 million is much more typical of the current DPP.

With a simulation model, the relative accuracy is usually determined through a validation procedure rather than statistically. In validation of the model used here, a large number of alternative assumptions and computational procedures were tested. The parameters fed into the current model provide estimates of 1974 and 1975 payments for all crops within 1 percent of the actual payments made by ASCS during these 2 years (*1, 2*). In another validation exercise, the model was run several times to test the impact of errors in input parameters and of incorrect specifications in the mathematical relationships. The validation work suggests that the estimates of future payments and the type of information presented in figure 3 are likely to be within 10 percent of true real-world values.

Assumptions concerning crop yields underlie the model and its accuracy. These assumptions concern the trend and expected value of future crop yields, the variance around this trend, and the correlation between yields of different crops. If future average yields are lower than expected, or if the standard deviation around these trends is higher than expected, the costs of a DPP increase substantially.

IMPLICATIONS

Since program and yield parameters are exogenous, the model provides the capability for analyzing the impact of alternative crop yields and modified DPP assumptions on program costs. For example the model can estimate the change in program costs that would result from changing disaster yields or the payment rate or from basing the payment on a yield that is less than the established yield. The model can also estimate the impact of changing allotments, as long as these are changed by the same proportion on all U.S. farms. However, the aggregate model cannot estimate the impact of changing the distribution of allotments among farms. Based on such capabilities, the model has been used to identify the impact of different yield assumptions and to estimate the impact of a number of modified disaster programs (*6, 7*).

Such information can be useful in the 1977 congressional deliberations concerning disaster payment provisions in the next farm act. With appropriate modifications in the parameters of table 1 and estimates of σ, the model can estimate expected indemnity payments in new areas that may be covered by the Federal Crop

Insurance Corporation. Such indemnity estimates are critical in the process of setting crop insurance premium rates in new areas.

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IN EARLIER ISSUES

The use of the term, government interference, as a synonym for government intervention has unfortunate connotations in the American vocabulary.

Kenneth L. Bachman
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April 1949