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ANALYSIS AND COMPARISON OF ALTERNATIVE ESTIMATIONS
OF CROP YIELD PROBABILITY DISTRIBUTIONS

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Subjective crop yield probability distributions (CYPD's) were determined to be important for predicting producers' decisions under risk (Zering, McCorkle and Moore 1987). Policy makers concerned with participation rates in Multiple Peril Crop Insurance (MPCI) and other farm programs have a demand for such crop yield information. Approximations of producers' subjective beliefs about CYPD's could be obtained using elicitation methods (Pease 1987; Nelson and Harris 1978).

Elicitation methods were identified to have two primary drawbacks. First, the time and money required to perform individual CYPD elicitations could be cost prohibitive for potential users. Second, validation difficulties could arise with elicitations. If elicited producers believed subjective responses would influence their economic welfare, then incentives existed to distort the CYPD estimates.

The crop yield capacity function (CYCF) (Gallagher 1983, 1986, 1987) was investigated in this paper as a procedure for deriving CYPD's to be compared with subjective CYPD's obtained by elicitation. A simple frequency distribution of historical crop yields was also tested for its ability to serve as an approximation to an elicited CYPD.

The potential for applying the CYCF as an inexpensive and practical technique for approximating the expected value of subjective CYPD's was supported in the study's estimation results. Extension personnel who present risk management seminars could use CYCF's to develop crop enterprise examples with improved estimates of perceived mean crop yields and with lower-bound values for CYPD variances. Researchers who had microcomputer access and ordinary least squares (OLS) software could apply the "corrected" OLS technique for estimating CYCF's and their associated CYPD's.

This paper was organized into four sections for the analysis and comparison of the alternative CYPD approximations: (1) advantages and limitations associated with elicitation, historical-frequency and CYCF techniques were identified, (2) data collection procedures used for each estimation technique were described, (3) goodness-of-fit tests were performed to compare historical-frequency and CYCF-derived CYPD's with aggregated-elicited CYPD's, and (4) implications of the analysis were discussed.

Aspects of Subjective CYPD Elicitation

The application of microcomputer technologies and psychological interviewing principles contributed to the development of innovative elicitation procedures (Pease 1987). A thorough review of elicitation principles and procedures was produced by Norris and Kramer (1986).

A set of guidelines, referred to as "the protocol", were developed by Pease and Black (1987) to conduct a CYPD elicitation interview. An interactive computer program (ELICIT) was written as part of the protocol (Pease and Black 1986). The conviction weights elicitation technique (Nelson and

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Harris 1978), a method for obtaining subjective responses, was implemented and quantified with the ELICIT program.

The protocol was applied in this study. Each elicitation required an hour to an hour-and-a-half to complete. Because of the time and expense involved in using the protocol, alternative techniques were explored to determine if subjective CYPD's were estimable for a decreased cost.

Historical-Frequency Approximations of Subjective CYPD's

An alternative procedure for estimating subjective CYPD's was investigated with the historical frequency hypothesis (HFH). In the HFH, producers were assumed to make no adjustment in their personal CYPD's for changes associated with new management practices or technologies. The notion that historical-frequency CYPD's were similar to elicited estimates of subjective CYPD's was tested with the HFH.

A researcher would expect the HFH to be rejected, if producers were Bayesian decision makers (Winkler 1972). HFH rejection would be predicted particularly for crops such as corn where dramatic technical impacts on yields have occurred.

Rejection of the HFH had important policy implications. For example, the size of a producer's deficiency payment or his MPCI coverage was partly dependent on an estimate of his mean historical yield. If the historical mean crop yield and the subjectively-perceived mean yield did not correspond, then producer incentives for participation in farm programs based on historical mean crop yields would not be correctly indicated.

CYPD's Derived from Crop Yield Capacity Functions

Another alternative estimation of a subjective CYPD was obtained with the CYCF technique. Crop yields were modeled as functions of prices, technology and environmental factors with CYCF's (Gallagher 1983, 1986, 1987). Capacity yields were defined in CYCF's as maximum yield levels that occurred when environmental conditions were ideal and production was assumed economically efficient.

Capacity and sub-capacity crop yields were assigned probabilities because environmental growing conditions were considered chance events. The CYCF-derived CYPD was defined as the set of probabilities that describe the size and frequency of crop yields occurring at or below the capacity yield.

A CYPD was derived from the following CYCF (Gallagher 1983):

$$YCAP_t = f_t(X1, X2, ..., Xn) + U_t \qquad \text{(Equation 1)}$$

Where: $YCAP_t$ = optimum crop yield output at time t, if environmental growing conditions were ideal. This was known as the "capacity crop yield" at time t.

$f_t(\cdot)$ = crop yield response function assuming economically efficient production and current technology, at time t.

X_i = ith explanatory variable in the crop yield response process.

U_t = downside yield variation at time t, caused by less-than-ideal environmental growing conditions, where $U_t \leq 0$.

The impacts of inputs, prices and technology on crop yields were specified in the CYCF functional form $[f_t(\cdot)]$ of Equation 1. The U_t error term was a distribution of stochastic deviations below a capacity yield level. The U_t distribution could be skewed or have other non-normal properties.

Procedures for measuring the one-sided U_t error term were called "frontier production function (FPF) estimations" in the econometric literature (Afriat 1972). The terms "frontier" and "capacity" were used interchangeably in this paper.

The CYCF models constructed before 1977 all specified the frontier as a deterministic value (Afriat 1972; Richmond 1974; Schmidt 1976). Estimation problems existed when deterministic frontier production functions were used for forecasting. Actual output could exceed the predicted capacity level. One solution was to model the frontier as a random variable with a stochastic frontier production function (stochastic FPF) (Aigner, Lovell and Schmidt 1977; Meeusen and van den Broeck 1977).

The stochastic FPF estimation procedure had an error term composed of two parts. One part of the error term was a normal probability density function (PDF) used to represent statistical noise encountered in the measurement of the frontier itself. Measurement errors on either side of the frontier were assumed equally likely, so the normal PDF for this part of the error term had its mean centered on the frontier. The other part of the error term was a PDF which measured the downside variation from the frontier. A CYPD derived from the stochastic FPF estimation procedure was the joint distribution of the composed error term.

Data Collection

The approaches used to obtain elicited, historical-frequency and CYCF-derived CYPD's were described below.

CYPD Elicitation Procedures. The elicitation sample size was determined using characteristics of the historical county-level corn yield probability distribution. Farm-level crop yield data were not used because they were unavailable. The selected study county was Brookings, South Dakota. County corn yield data were used to determine the sample size because corn acreage and production volume were the largest of any crop in Brookings County (South Dakota Crop and Livestock Reporting Service [SDCLRS] 1987).

Sixty-two randomly selected Brookings County owner-operators were interviewed during March-July 1987. The elicited producers were those who had previously or currently received payments from the USDA farm programs. Corn, soybeans and oats were dominant crops in acreage and production in Brookings County, and the CYPD's elicited from the producer sample consisted primarily of these three crops.

<u>County-Level Data for CYPD Estimation.</u> Sample-wide aggregations of the elicited CYPD's were developed to provide comparable results with the historical-frequency and CYCF-derived CYPD estimations that were determined with county-level data.

A technique similar to Bessler's (1980) was used to convert individual CYPD elicitation results into aggregated-elicited CYPD's. The Brookings County elicitations were aggregated by using an averaging method which assigned equal weights to the interviewed producers' conviction weights.

County-level crop yield data were determined to underestimate farm-level CYPD variances in previous research (Eisgruber and Schuman 1963; Fulton, King and Fackler 1988). When the aggregated-elicited CYPD's and the county-level CYPD's derived from the HFH and CYCF procedures were compared, differences in their respective estimated variances were expected to be observed.

The historical-frequency CYPD's were determined using the 1957-1986 time span of data that was also employed in the CYCF estimations. The same data set was applied because a comparison of a historical-frequency CYPD was made with a CYCF-derived CYPD as well as with an aggregated-subjective CYPD.

Estimation of CYCF-Derived CYPD's

The CYCF model was used to test the relationship between the dependent variable, crop yield, and four major classes of independent variables (Gallagher 1983; Houck and Gallagher 1976): (1) output and input price variables, (2) government farm policy variables, (3) technological trend variables, and (4) environmental variables. The model specification and variable definitions for the CYCF were:

$$YCAP_t = \alpha + \beta(PCROP_{t-1}/PFERT_t) + \delta(PACRES_t)$$

$$+ \Phi(TREND_t) + U_t \qquad \text{(Equation 2)}$$

Where: $\alpha, \beta, \Phi > 0, \quad \delta < 0, \quad U_t = (\Omega_t - \theta_t), \quad U_t \leq 0, \quad \theta_t \geq 0$

Variable
Definitions:

$YCAP_t$ = capacity crop yield
α = constant term
β, δ, Φ = coefficients of the independent variables
$PCROP_{t-1}$ = lagged crop price
$PFERT_t$ = weighted fertilizer price
$PACRES_t$ = proportion of acres harvested, proxy for Farm Program influence
$TREND_t$ = technological trend variable

U_t = the environmental variable, measured as the total disturbance term beneath the capacity crop yield.
Ω_t = normally-distributed measurement error, centered on the capacity yield.
θ_t = part of the error term representing production below the capacity yield.

The 1957-1986 historical series of harvested county-level crop yield data for corn, soybeans and oats in Brookings County, South Dakota were the basis for estimating the YCAP, variable of Equation 1 (South Dakota Crop and Livestock Reporting Service [SDCLRS], 1957-1987). The number of years of crop yield data analyzed was based on the history of South Dakota fertilizer usage.

Observable lagged output prices were used as a simple approximation of producer expectations in this model (Nerlove and Bachman 1960). CYCF's were specified with current fertilizer prices to measure the producer incentive to employ inputs which enhance crop yield growth. Derived demand theory was used to specify an inverse relationship between the output and fertilizer price variables.

A Laspeyres price index for fertilizer was developed. The prices of nitrogen, phosphorus and potash prices were weighted by their respective South Dakota usage rates in 1972 (SDCLRS 1973). The 1972 base year was a transition year in the U.S. between the farm-program-dominated era of the 1960's and the export-dominated agriculture of the 1970's.

A proxy for cropland diversion programs was used to represent the effect of federal farm policies on crop yields. Set-asides and similar farm programs encouraged producers to idle their less productive lands, and to farm the remaining land more intensively (Houck and Ryan 1972). Planted crop acreage (PACRES) was used as a proxy for farm program influences (Gallagher 1986). Brookings County's principle crop acreages during the 1957-1986 period were obtained from SDCLRS publications.

Increased agricultural productivity was modeled as a function of technological change (Griliches 1957; Hayami and Ruttan 1970). A linear crop yield trend was selected as an independent variable for corn, soybeans and oats crops in Brookings County. The selection was made from a variety of linear and curvilinear alternatives using the Box-Cox transformation procedure (Judge, et. al. 1985).

Environmental impacts on crop yields were investigated in previous research. Temperature, precipitation and soil moisture variables were explicitly modeled in some studies, and implicitly with crop yield indexes in others (Stallings 1961; Doll 1967). The CYCF was specified to implicitly capture environmental impacts in the error term of the estimation (Gallagher 1983).

Characteristics of the CYCF error term were a factor in selecting the econometric estimation technique. Stochastic CYCF's were estimated with a procedure known as corrected ordinary least squares (COLS) (Forsund, Lovell and Schmidt 1980). [1] The constant term of the COLS regression is upwardly-

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[1] Maximum likelihood (ML) methods were used by Gallagher (1983) to estimate CYCF's. ML was attempted in this study, but estimation convergence was not achieved. When tested with Monte Carlo techniques, only a small efficiency gain was obtained with ML as compared to COLS (Olson, Schmidt and Waldman 1980). The theoretical advantages of ML relative to COLS were judged as minor,

adjusted, based on the error term's distributional assumptions, to estimate the capacity crop yield as a dependent variable.

CYCF Estimation Results. Stochastic CYCF's were estimated for Brookings County corn, soybeans and oats crops with the COLS procedure. The corn and oats crop yields were modeled with all the independent variables of Equation 2. The soybean yield equation did not include the proxy variable for the farm program.

When equation 2 was fitted to the corn, soybean and oats yield data, multicollinearity occurred among the independent variables. The trend variable for all three crops had the expected positive coefficient. However, the crop-price-to-fertilizer-price ratio coefficient and the farm program variable coefficient did not have the predicted signs.

The price ratio and farm program variables did have the predicted signs when they were modeled as sole explanatory variables. A joint F-test was performed to determine which variables statistically explained the variation in crop yield (Pindyck and Rubinfeld 1981). The F-test results were used as a basis to respecify the CYCF model of the soybean and oats yields as functions of single technology trend variables.

Modeling of the corn yield was problematic. The coefficient of the price-ratio did not have the expected positive sign, but the price-ratio was statistically significant at the 0.10 level. A decision was made to report the results for the corn CYCF's estimated with and without the price-ratio variable. Eliminating the price-ratio variable had the effect of creating a positive bias in the crop yield's econometric estimation.

There were two reasons for estimating the CYCF with the price-ratio variable excluded. First, the price-ratio variable was probably affected by an interaction with farm program and technological impacts, and therefore was not the independent measure of the market incentives specified for the model. Second, the purpose of the using the CYCF was to estimate the producer's subjective CYPD, and a producer's CYPD be would likely be reflective of the interactions that would be contained in the unexplained variance associated with the CYCF-derived CYPD.

The results of the two COLS-estimated corn CYCF equations, along with the soybean and oats CYCF's, were presented in Table 1. The t- and F-values were statistically significant at the 0.10 level for all three crops. The parameter estimates for the CYCF-derived CYPD's were used to indicate that the mean (μ) corn yield was 11.31 bu/ac below the capacity level when $\beta \neq 0$, and 14.93 bu/ac below when $\beta = 0$. The mean soybean and oats yields were, respectively, 5.28 and 10.03 bu/ac below capacity.

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and did not justify the extra trouble required to implement ML (Olson, Schmidt and Waldman 1980). COLS procedures were selected as an alternative method to estimate CYCF-derived CYPD's.

Comparison of the Alternatively Estimated CYPD's

Three pairwise CYPD comparisons were performed: (1) CYCF-derived CYPD's were compared with aggregated-subjective CYPD's, (2) CYCF-derived CYPD's were compared with historical-frequency CYPD's, and (3) aggregated-subjective CYPD's were compared with CYPD's derived under the HFH assumption.

The Kolgomorov-Smirnov (K-S) test was used to test the goodness-of-fit among the historical, capacity and aggregated-subjective CYPD's (Table 2). The K-S test was distribution-free: no assumption had to be made as to the parameters of the underlying distribution function to perform the test.

The null hypothesis that the CYCF-derived CYPD's were similar to the elicited CYPD's was not rejected for the corn ($\beta=0$) and soybean crops (Table 2). The mean yields of the CYCF-derived CYPD's closely approximated the corresponding elicited mean yields. The CYCF-derived CYPD's for corn and soybeans measures had one important shortcoming in the approximation of the elicited CYPD's. The variances of the elicited CYPD's were 1.72 to 2.54 times larger than the CYCF-derived CYPD variances (Table 1). The CYCF-derived CYPD's could serve as approximations to subjective CYPD's by using a "rule of thumb": upwardly adjust the capacity variance by a factor of two to three.

Oats was a crop in Table 2 where the elicited CYPD was not well modeled by either the CYCF-derived or historical-frequency CYPD's. The COLS-estimated CYCF function was not a good statistical fit to the county level oats yields (Table 1). One hypothesis that merited further research was that Brookings County producers were overly optimistic about oats' crop yield potentials.

The historical-frequency CYPD's were determined to be dissimilar from both the capacity and elicited CYPD's for all three crops. The use of CYPD's derived from historical frequencies was not a proxy for aggregated-subjective CYPD's, nor were they similar to the CYCF-derived CYPD's.

Implications of the Analysis

CYCF's were determined to provide superior estimates of subjective CYPD's as compared to historical crop yield frequency approximations. The research results supported the notion that producer CYPD perceptions included adjustments for new technologies and management practices.

COLS was determined to be an inexpensive technique for estimating a CYCF-derived CYPD. Researchers investigating impacts of variable crop supplies on county elevators might employ COLS as an estimation tool.

If a COLS estimation of a CYCF was performed with county-level crop yield data, then the expected value of an elicited farm-level CYPD could be approximated, although the perceived farm-level crop yield variance would likely be underestimated by a factor of two to three.

Elicitation techniques were still the best estimators of subjectively-perceived CYPD's, but COLS might potentially be a substitute in regions where farm-level crop yield data could not be gathered economically.

Table 1. COLS Estimation Results for Stochastic Corn, Soybeans and Oats CYCF's in Brookings County, South Dakota.

Estimated Parameter	Crop Modeled by CYCF Technique			
	Corn, $\beta \neq 0$	Corn, $\beta = 0$	Soybeans	Oats
α Coefficient	84.31 (5.44)*	46.10 (8.08)	16.84 (8.22)	51.38 (15.06)
β Coefficient	-4375.00 (3.22)	N/A	N/A	N/A
Φ Coefficient	1.70 (7.74)	1.68 (6.60)	0.57 (6.50)	0.62 (3.41)
$\bar{R}^2$	0.70	0.60	0.59	0.27
F-Statistic	34.28	43.63	42.18	11.64
Capacity Variance ($\sigma^2 = \sigma^2_\theta + \sigma^2_\Omega$)	225.32	353.23	44.34	168.89
θ_t Mean ($\mu = (\sqrt{[2/\pi]}) \cdot \sigma_\theta$)	11.31	14.93	5.28	10.03

*Numbers in parentheses were t-values. A 90% confidence limit was used. The critical t-value at the 0.10 level was 1.70. The critical F-value at the 0.10 level was 3.35.

Table 2. Goodness-of-Fit Tests of Alternative CYPD Estimations[*].

Distributions Tested for Goodness-of-Fit	CYPD's Compared Using the Kolgomorov-Smirnov Test			
	Corn, $\beta \neq 0$	Corn, $\beta = 0$	Soybeans	Oats
Elicited CYPD Compared to Capacity-derived CYPD	Reject (D=0.39)	Not Reject (D=0.22)	Not Reject (D=0.17)	Reject (D=0.37)
Elicited CYPD Compared to Historical-Freq. CYPD	Reject (D=0.42)	Reject (D=0.42)	Reject (D=.40)	Reject (D=0.49)
Capacity Derived CYPD Compared to Historical-Freq. CYPD	Reject (D=0.63)	Reject (D=0.63)	Reject (D=0.53)	Reject (D=0.40)

[*] When the null hypothesis was not rejected in these tests, the CYPD's were determined to be similar. A **90% confidence limit** was used to determine the critical value in all the tests. The D value of the K-S measured the maximum absolute distance between the CDF's being compared.

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Perversion of Risk Aversion: An Application to Farm Planning and Intertemporal Resource Allocation

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Vast areas of the Texas Southern High Plains are undergoing a transition from irrigated to dryland crop production. Due to limited recharge of the Ogallala Aquifer in the region, irrigated acreage has declined by 27 percent from 1974 to 1984 (Texas Water Development Board). Continued mining of the Ogallala can be expected to increase pumping costs and reduce well yields. These two factors will ultimately diminish irrigated crop profitability. As acreage reverts from irrigated to dryland, crop production profitability is expected to decline and the variability of these net returns would increase. It is this transition from an intensive agriculture to an extensive one (i.e. irrigated to dryland) which offers a unique framework to evaluate the temporal and intertemporal aspects of optimal crop mix selection and resulting path of groundwater use under risk considerations.

Optimal crop mix selection under risk has received much attention in the literature over the past two decades (Adams et al., Pederson and Bertelsen, Barry and Robison). An early study by Scott and Baker used annual historic net returns in a quadratic programming model to evaluate optimal farm plans. This was one of the first studies to explicitly account for government price supports and their impact on net return risk in a whole farm context. One limitation of the Scott and Baker study and other similar studies is the use of annual net returns to express crop production risk, particularly if one considers multi-year crop rotations. Shrestha et al. indicate that a multi-period risk specification may be necessary in farm planning to account for multi-period investment alternatives and the seasonal acquisition of inputs (i.e. renting cropland, hiring labor, etc.). Relative to the Texas High Plains, a multi-year formulation is necessary to account for crop rotations produced under limited soil moisture, adjustment in commodity base acreage as well as the intra and inter-seasonal allocation of irrigation water.

Following the suggestion for additional research in the area of intertemporal risk preferences by Love and Robison, this study focuses on evaluating adjustments in crop mix and rate of groundwater extraction over time under different risk aversion scenarios. Because groundwater depletion tends to be a long term process, a multi-year recursive modelling structure was adopted. This recursive structure allows one to assess the temporal and intertemporal pattern of crop mix, path of net returns, and change in groundwater cost and availability across risk aversion scenario during the transition to dryland crop production.

Models and Procedures

Two general models were used to predict producer crop mix adjustments and rate of groundwater extraction for a representative farm on the Texas Southern High Plains. A multi-year/multi-crop growth simulation model was used to generate input data for the whole-farm optimization model. The multi-year/multi-crop growth model provided crop yield estimates by irrigation regime and crop rotation scheme under stochastic weather conditions. The firm level optimization model was capable of adjusting groundwater availability and cost as well as update objective function values over time depending on the quantity of water pumped in the previous time periods.

Programming Model

A firm-level Multi-Period Recursive Quadratic Programming (MPRQP) model was developed to evaluate optimal temporal crop rotation selection and the