Normative Supply Response Analysis under Production Uncertainty: Irrigated Multicrop Farming Sector of Sudan

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Abstract: Sudan's irrigated subsector is the largest in sub-Saharan Africa. Farming is practised under a scheme-mandated rotation with highly centralized decision making. Under this system, labour is the major input for which the tenant has allocation flexibility both during the season and across the three crops grown, sorghum, cotton, and groundnuts. This paper analyzes the risk attributes of the production technology and measures farmer's attitudes towards risk in the irrigation schemes of Sudan. Stochastic production functions are specified where risk increasing and risk reducing input effects are allowed. Single-equation and systems procedures are employed to estimate the parameters of the first two moments of the distribution of crop yields. The analysis supports the existence of aggregate indices for weeding and harvesting labour for cotton and sorghum, while the hypothesis of separability in hired and family labour is rejected. The form of labour contract for hired labour is found to have significant implications on its production risk effects. When hired labour is paid in cash, production risks increase, as is the case with cotton and sorghum. When sharecropping takes place, as in groundnuts, production risks decrease with increased labour use. Supply behaviour of the tenant farmers under production uncertainty is simulated using a farm programming model.

Introduction

In recent years, the main concern of policy makers in Sudan as well as in most developing countries has been the large external debt and food security. To enhance agricultural productivity and export earnings, emphasis has been placed on measures directed towards changing the structure of incentives to agricultural producers in order to promote adoption of new technologies and improved farming methods. While these methods and technologies raise yield levels, they also influence yield variability and production risks and hence have uncertain effects on the economic returns and welfare of the agricultural producers. Consequently, if farmers respond to risk, the rate of adoption and diffusion of new technologies in agriculture depends not only on their yield effects but also on their risk effects. Hence a comprehensive characterization of the risk attributes of the production technology and farmer attitudes towards risk is crucial to designing appropriate policy measures to bring about the desired adjustments in agricultural supply.

In this paper, a normative supply response model is developed to analyze supply decisions under production uncertainty in the multicrop farming system of the Rahad irrigation scheme in the Sudan. Stochastic production functions are specified where risk increasing as well as risk reducing input effects are allowed. Single equation methods as well as systems procedures are employed to estimate the parameters of the first two moments of the distribution of crop yields.

Various separability tests were performed on family, hired, weeding, and harvesting labour classes. The manner in which hired labour is paid is found to have significant implications on its risk effects. While hired labour increases production risks in cotton and sorghum (where cash wages are paid), it reduces production risk for groundnuts (where sharecropping prevails).

An average farm programming model is constructed to simulate supply behaviour of the Rahad tenants under production uncertainty. The generated response functions are found to be more elastic when factor inputs are allowed to influence production risks.

Production Uncertainty and Stochastic Technology

One way to represent random technology is by a conditional probability distribution function rather than a single function of output (Day, 1965; Anderson, 1973; Roumasset, 1976; and Antle, 1983):

(1) $F(Y/X, \beta)$.

Alternatively, a random disturbance term can be appended to a deterministic neoclassical production function to represent stochastic technology (the production function representation):

(2) $Y = f(X, \beta, \varepsilon)$.

Of major concern in incorporating error terms are the implications of alternative specifications of the stochastic component ε on econometric estimation of the mean function (Marschak and Andrews, 1944; Mundlak and Hock, 1965; and Zellner, Kmenta, and Dreze, 1966).

Part of the variability in crop yields is explained by controllable factors such as irrigation, fertilizers, improved seeds, cultivation methods, etc. (Day, 1965; Fuller, 1965; de Janvry, 1972; Just and Pope, 1978; and Pope and Kramer, 1979). If agricultural producers can influence production risks by varying the levels of input use, then factor demands under risk aversion are different from those under risk neutrality. A risk averter will use more (less) of the risk reducing (increasing) factor than the risk neutral firm (Pope and Kramer, 1979).

Various specifications have been used to represent stochastic technology. Just and Pope (1978) have shown that some popular formulations of stochastic production functions are very restrictive. The main deficiency of the common forms is the implication that all factors are risk increasing and thus are all used less under risk aversion (Ratti and Ullah, 1976; and Batra and Ullah, 1974). According to several reasonable risk considerations suggested by Just and Pope (1978), the log-linear and multiplicative disturbance forms are found lacking. An alternative, more flexible form is proposed by Just and Pope (1978):

(3) $Y = f(X, \beta) + h(x, \alpha)\varepsilon$.

Model (3) allows for separate effects of factor inputs (X) on the deterministic (f) and the stochastic (h) components of production. This formulation also allows for both risk increasing and risk reducing effects (e.g., $h' \gtreqless 0$). Model (3) is used in the present study.

A multistage nonlinear generalized least squares (MNGLS) procedure has been suggested to estimate the parameters β and α of model (3) (Just and Pope, 1978; and Griffiths and Anderson, 1982). The suggested procedure extends the error components approach of Hoch (1962), Wallace and Hussain (1969) and Fuller and Battese (1973) to nonlinear models with both firm and time disturbance components. The MNGLS is briefly outlined below.

For the model in (3), let $E[\varepsilon] = 0$ and $V(\varepsilon) = \sigma$. Therefore, $E[Y] = f(x, \beta)$ and $V(Y) = h^2(x, \alpha)\sigma$. The MNGLS estimators of β and α are obtained with the following procedure:

(a) A consistent estimator for β is obtained in the first stage by nonlinear least squares (NLS) from the regression of Y on (x, β). A consistent estimator of $h(x,)$ is derived as:

(4) $\hat{U} = Y - f(x, \hat{\beta}) = h(x, \alpha)\varepsilon$.

(b) An NLS estimator of α is then obtained in the second stage from the regression of $\hat{U}^2$ on $\hat{h}^2(x, \alpha)$. The consistent estimator $\hat{\alpha}$ is then used to derive $h(x, \hat{\alpha})$.

(c) An NLS estimator of β is then obtained from the weighted regression of Y^* on $f^*(x, \beta)$, where:

(5) $(Y^*, f^*) = [\hat{h}(x, \hat{\alpha})]^{-1} [y, f(x, \beta)]$.

The estimator $\hat{\beta}$ obtained in (c) (the MNGLS) has been shown to be consistent, asymptotically efficient, and unbiased under a broad range of conditions (Just and Pope, 1978). The asymptotic efficiency of the MNGLS procedure has also been shown to hold when the disturbance term ε includes both cross-section as well as time-series components in Just and Pope (1978) and Griffiths and Anderson (1982).

While data generated by controlled experiments do not contain certain behavioural restrictions, survey data, on the other hand, represent optimal choices of the sampled firms. When working with survey data, input and output levels are assumed to be jointly determined in the first-order equations of the optimizing firm. According to Marshak and Andrews (1944), production function disturbances are transmitted to the system of first-order-condition equations of factor demands and output supply leading to endogeneity of input levels. Therefore, the application of the above described procedure could result in simultaneous equation bias in parameter estimates when survey data are employed. Hoch (1962), and Zellner, Kmenta, and Dreze (1966) have shown that production disturbances, which are unknown at the time of decision making, are not transmitted to factor-use equations when maximization of expected profits is assumed.

To allow for efficiency gains when known variance components are likely, the MNGLS procedure is modified to handle the simultaneity problem. The NLS estimator obtained in step (a) of the above procedure is replaced by an instrumental variable estimator. This is equivalent to the nonlinear two-stage least squares (N2SLS) procedure. The N2SLS yields consistent estimators of β, $f(x, \beta)$, and hence U in the step (a) (Amemiya, 1974; and Gallant and Jorgenson, 1979). In stage two (b), the heteroscedastic structure $h(x,)$ is estimated using the consistent N2SLS estimator of U obtained in (a). The consistent estimator of $h(x, \alpha)$ is then used in the third stage weighted N2SLS regression of Y^* on $f^*(x, \beta)$ to obtain the instrumental variable, multistage nonlinear GLS (IMNGLS) estimator of β.

With joint production assumed for the three crops modelled here, across-equation correlations are assumed to exist between the production disturbances in the three technology functions to be estimated. A system procedure is yet more efficient than the single-equation methods described above. A nonlinear simultaneous equation method that corrects for heteroscedasticity and cross-equation correlations is employed. This procedure is referred to here as the iterative nonlinear three-stage least squares (IN3SLS). The asymptotic properties of the nonlinear systems estimators are established in Barnett (1976), Amemiya (1977), Gallant (1977), Gallant and Jorgenson (1979), and Gallant (1987). Both the IMNGLS and the IN3SLS procedures are employed to estimate the technology parameters of the empirical model developed below.

Econometric Model

Cotton, groundnuts, and sorghum are grown in the Rahad scheme under regular irrigation and mechanical power. A fixed cropping pattern is imposed on the tenants. Levels of most of the production inputs are determined by the scheme administration (acreage, seed rates, and chemical and mechanical inputs). Thus, except for family and hired labour (working capital) allocations, other inputs are considered fixed for all farmers. Crop yields, however, are responsive to the quantity and quality of the labour and managerial resources under farmer control. Crop yield functions are thus specified to depend on labour allocations, managerial ability and skill, as well as sowing dates. Weeding and harvesting are identified to be the major activities that employ farmer resources.[2]

Three yield equations are specified to represent the multicrop production technology of the Rahad tenants. Flexible functional forms (the translog and the generalized power) are used in estimating the mean and variance of yield functions of model *(3)* and for testing for the technology structure. The unrestricted form of the functions has six factors: sowing date, years in farming, family and hired weeding labour, and family and hired harvesting labour. While sowing dates and years of farming are considered exogenous, weeding and harvesting family and hired labour are assumed endogenous. Sets of instrumental variables are constructed for each of the endogenous labour variables in each of the three yield equations. The set of instrumental variables include age, sex, farming years, education, distance between tenancies and homesteads, family size, average wage rates, sowing, weeding and harvesting dates overlap indices, labour recruitment methods, labour origin, etc.

Symmetry is imposed on the translog function ($\beta_{ij} = \beta_{ji}$). Other structural features are statistically tested using the unrestricted translog function proposed by Christensen *et al.* (1971):

$$(6)\ ln\ Y_k = ln\ \beta_{0k} + \sum_{i=1}^{N} \beta_{ik}\ ln\ X_{ik} + \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{ij,k}\ ln\ X_{ik}\ ln\ X_{jk}.$$

Following Berndt and Christensen (1973), the following tests are performed on the translog function:

(a) **Homogeneity:** The function is homogeneous of degree r if and only if:

$$(7)\ ln\ F(\lambda X_1, ..., \lambda X_n) = ln\ F(X_1, ..., X_n) + r\ ln\ \lambda.$$

Constant returns to scale ($r=1$), therefore, imply the following restrictions on the translog production function:

$$(8)\ \Sigma\ \beta_i = 1, \text{ and}$$

$$(9)\ \sum_i \beta_{ij} = \sum_j \beta_{ij} = 0 \text{ (zero row and column sums).}$$

(b) **Functional separability**: For inputs i and j to be separable from input k in the production function $F(X)$, the following must hold:

$$(10)\ F_j\ F_{jk} - F_j\ F_{ik} = 0,$$

where F_i and F_{ij} are the first and second derivatives of F.

The translog function condition *(10)* is satisfied with either of the following alternative restrictions (Berndt and Christensen, 1973):

(i) **Linear separability restrictions**: which reduces the translog to the logarithmic Cobb-Douglas function ($\delta_{ik}=\delta_{jk}=1$):

$$(11)\ \beta_{ij} = \beta_{jk} = 0.$$

(ii) **Nonlinear separability conditions**: which imply that $\delta_{ik} = \delta_{jk}$ but not necessarily equal to one:

$$(12)\ \beta_i = \beta_j - \beta_{ij}\ /\beta_{jj}, \text{ and}$$

$$(13)\ \beta_{ii} = \beta_{ij}^2/\beta_{jj}.$$

The study tested for the existence of aggregate indices of the various labour services used by the production process.

(c) **Monotonicity and convexity**: These are tested for indirectly by evaluating F_i and the bordered Hessian at various data points.

The results of the various structural tests failed to support the hypothesis that family and hired labour provide homogeneous services in cotton and sorghum. Complete separability was accepted for groundnuts. The data supported the hypothesis that aggregate indices for weeding and harvesting labour services exist for cotton and sorghum. This result implies that wages paid to hired labour cannot be used as a proxy for the marginal value product of family labour.

Optimal sowing was found to reduce production risks significantly. Hired labour is risk increasing for cotton and sorghum. The reverse is true for groundnuts. A sound interpretation could be found in the form of labour contracts; e.g., the way hired labour is paid. While sharecropping arrangements dominate groundnuts production, cotton and sorghum hired labour are paid cash wages. Moreover, cotton and sorghum receive the highest attention and care from the farming family as they are the main food and cash crops for the household. Family labour is more skilful than hired labour in cotton and sorghum production.

Programming Model

An average farm programming model is constructed in this section to study the supply behaviour of agricultural producers in the scheme and estimate their risk preference parameters.

The two-moments (E-V) expected utility model is used to represent the risk preferences of producers (Markowitz, 1959). In this model, expected utility U is expressed as a quadratic function of the first two moments (mean $E[N]$ and variance $V(N)$) of the distribution of random economic returns N:

$$(14)\ U(N) = E[N] - [QV(N)]/2,$$

where Q is the Arrow-Pratt measure of *ARA*. Equation *(14)* is maximized subject to the technical, institutional and resource constraints defining the feasible set of the choice problem. The parameters of model *(3)* (β and α) represent the technology constraints of the system. Accordingly, expected net return $E[N]$ is a function of the parameters of the mean yield functions $f(x, \beta)$, crop areas A, and net returns per unit of output P:

$$(15)\ E[N] = A'R(x, \beta, P),$$

where A is a 3×1 vector of crop areas and R is a 3×1 vector of net returns per unit area. Similarly, the variance of net returns $V(N)$ is a function of the parameters of the variance of yield function $h(x, \alpha)$ for crop areas A and P:

$$(16)\ V(N) = A'V_R(X, \alpha, P)A,$$

where V is the 3×3 symmetric covariance matrix of net returns per unit of area. According to model *(3)*, the diagonal elements V_k (V_{ii}) are functions of the Xs (variance of yield functions). The off-diagonals of V (the yield covariances V_{ij} for $i \neq j$) are, on the other hand, considered constants. The residual covariances of the IN3SLS econometric estimation of model *(3)* are used as consistent estimates for the yield covariances V_{ij} of V_k. The restricted forms of the generalized power yield functions are estimated for the three crops under study to be used in the programming model. Other resource constraints include labour and land constraints. Construction of the model parameters is discussed in detail in Hassan, D'Silva, and Hallam (1987).

The general interactive optimizer (GINO) is used to solve the model. Different solutions to the model are generated by varying the coefficient of *ARA* (Q). Simulated solutions are compared to the actual farm plans. The value of Q that best simulates observed choices of the farmers was found to be 0.001. The same coefficient (0.001) was estimated by Hassan, D'Silva, and Hallam (forthcoming) for the dryland traditional farmers. *This implies that risk preferences of agricultural producers in the irrigated commercial agriculture and dryland subsistence farming are not significantly different.* Response functions are estimated for different behavioural and structural specifications to analyze the risk effects of factor inputs. The following scenarios are employed to represent different specifications of the model:

(a) **Risk Neutrality:** Q is assumed to be zero and thus the effects of factor inputs on the second moment of the distribution of returns do not affect farmer decisions.

(b) **Risk Aversion and Zero Risk Effects:** In this formulation of the model, Q is positive but farmer actions cannot influence production risks. In other words, the diagonal elements as well as the off-diagonals in the covariance matrix of net returns V are constant.

(c) **Risk Aversion and Nonzero Risk Effect:** Q is positive and factor inputs have nonzero risk effects. This implies that farmers are allowed to alter production risks by optimally choosing input levels; e.g., the diagonal elements of the V_k are functions of input levels X.

The risk averse firm was found to use more of the marginally risk-reducing factor (family labour in cotton and hired labour in groundnuts) than the risk neutral firm. The reverse is true for the risk-increasing factor (hired labour in cotton and family labour in groundnuts). Risk neutral firms, on the other hand, produce more and thus use more of all inputs than risk averters when zero risk effects are assumed. Demand for factor inputs is more elastic when their risk effects are taken into consideration.

Summary and Conclusions

The uncertain nature of farming and the important role of risk in supply decisions necessitate comprehensive characterization and measurement of the structure and risk attributes of the production technology as well as farmer risk attitudes. A normative supply response model was developed to study the supply behaviour of agricultural producers in the irrigated farms of Sudan under production uncertainty. Stochastic production functions were specified for the three crops grown. Risk-increasing as well as risk-reducing input effects were allowed in the stochastic representation. Single equation methods (IMNGLS) as well as systems procedures (IN3SLS) were employed to estimate the parameters of the first two moments of the distribution of crop yields. Significant efficiency gains were realized in parameter estimation when the heteroscedastic structure and the cross-equation correlation of production disturbances were taken into consideration.

Separability tests showed that family and hired labour perform distinct tasks and did not support their aggregation. The existence of aggregate indices for weeding and harvesting labour is supported. The way hired labour was paid influences its risk effects. Hired labour was found to increase production risks when sharecropping prevails in groundnut production. Family labour was found to be risk reducing in cotton and sorghum production.

An average farm programming model was constructed. The estimated mean and variance of yield functions were employed in the two-moment model of expected utility maximization. An average coefficient of ARA was estimated by the model to be 0.001. The same degree of risk aversion was estimated for Sudanese farmers using traditional production methods in rainfed areas (Hassan, D'Silva, and Hallam, 1988).

Supply responses of the average farmer are simulated under different behavioural and structural assumptions. As expected, risk averse farmers were found to demand more of the risk-decreasing factor than the risk-neutral firm. This fact, that the rate of adoption and diffusion of improved production technologies and farming methods is dependent not only on their effects on average yield levels but also on their risk effects, has policy implications. This points out the importance of studying the risk attributes of production technology to designing successful and effective agricultural development policies.

Notes

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[2]A detailed discussion of the Rahad farming system is found in D'Silva and Hassan (1987).

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DISCUSSION OPENING—*Joachim von Braun* (International Food Policy Research Institute)

Hassan, D'Silva, and Hallam examine the important issue of risk attributes of new production technology and farmer attitudes towards risk in the context of a scheme in Sudan's irrigated multicrop farming sector. Yield variability in three crops—sorghum, cotton, groundnuts—is the focus of the risk-related analysis. Special emphasis is placed on labour as much of other variable input use is considered predetermined, given the scheme production regulations for land use, water, seed, and fertilizer. Farmer deviations from production prescriptions, quite common under such conditions, are not evaluated.

The skillfully applied approach to evaluate some causes and farmer responses to yield variability deals with a subset of the risk issue. The role of new production technology as a (potential) cause of risk is, however, not isolated, because all sample farmers are inside the scheme and basically face the same technology options. A with/without new technology situation is not depicted. A descriptive account of the change from what to what technology that may have induced a shift in the production function would be desirable. According to the analysis, different skills, size of enterprise (degree of labour use), and level and timeliness of cropping practices determine yield variability in the expected way. One would like to know the length of the time period (crop seasons) of observation to which "variability" refers. Cross-sectional assessment of yield differences is certainly inappropriate if risk and risk response are to be evaluated.

The paper raises a number of interesting methodological issues. One relates to the yield functions: latent unobserved variables such as soil conditions (probably not so important in this case) and irrigation water/drainage conditions (probably important here) tend to determine factor use (labour) and yield levels. Detailed technical information is required to account for such relationships. If available, it should be used in the yield functions. Otherwise, labour productivity tends to be overestimated. If not available in the data set used, the results are to be interpreted with caution. I suggest two broader policy research issues related to *supply response* and to *risk* in irrigated agriculture for further discussion.

1. Supply response in irrigated agriculture cannot be assessed in isolation. Intra- and intersectoral relationships come into play. If irrigation schemes are surrounded by rainfed agriculture, the opportunity cost of labour changes with rainfall and supply of hired labour may accordingly change dramatically. In other environments, nonagricultural sector

employment may fluctuate and impinge on labour allocation to irrigated agriculture and thus yields.

2. Much of the production risk in irrigation schemes relates not to farm level technology problems but to management of schemes and to policy.

Year-to-year and seasonal labour use in irrigation schemes is much determined by labour's alternative employment opportunities. Where labour has the short-term option to move between irrigated and rainfed agriculture, good rains are bad for yields in irrigation schemes and vice versa. An irrigation scheme in West Africa observed through drought years and good years shows labour-input-related yield fluctuations between 6 t of paddy (drought years) and 3.5 t (years of good rainfall pulling labour into the upland crops). Obviously this yield variability is *not* reflecting a *risk* of the irrigation technology but is the result of efficient short-term factor reallocation. It is also relevant in drought-prone Sudan. The point is: supply response in a subset of agriculture—e.g., the irrigated sector—cannot be evaluated in isolation without considering the factor movements (i.e., labour) between the subsectors of agriculture and the rest of the rural economy.

Yield risk and production risk in irrigation schemes are induced by management problems (water and cultivation services) and input supply problems (fertilizer and seed). The individual farmers may be affected by such risks differently within supervised schemes. Location of fields and status of farmers impinge on the outcome of, for instance, who gets ploughing services on time, who gets fertilizer in sufficient quantities, or which pumps are operated if fuel is in short supply.

In the Sudanese schemes with area allotment by crop, an additional factor comes into play: the area allotment may change due to changing policy priorities. Foreign exchange needs and international competitiveness (cotton) and domestic food needs (sorghum) do change the area allotments. The irrigated food crop area, for instance, was substantially expanded as a consequence of the drought in Sudan in 1983-84. Thus the drought and policy in response to drought were transmitted into the irrigated subsector. Production patterns changed. Therefore, risk in the irrigation subsector is not only risk in yields of crops actually grown but also entails the risk of policy changes.

We have an interesting and stimulating paper here, but one would like to know more about the technical change actually assessed. Yield variability as such is not a measure of production risk and uncertainty. We need to know more about the nature of the data set we are looking at here (time series and seasons). Yield measures for changing cotton varieties in the state-ordered variety choices pose a problem of comparison.

Two broader policy research issues certainly deserve more attention. *Supply response* in irrigated agriculture cannot be comprehensively assessed in isolation. Relationships to other agricultural subsectors and nonagricultural sectors—where relevant—have to be explicitly included in the analysis. Production *risk* in irrigated agriculture relates closely to management failures of schemes and to policy changes in supervised agriculture as is the case in Sudanese irrigation schemes. Yield risk is only a subset of the risk story under these conditions.

GENERAL DISCUSSION—*K. Sain, Rapporteur* (Bidhan Chandra Krishi Viswavidyalaya)

Questions were raised about the coverage of different types of risk and uncertainty and the efficacy of the production-function analysis. Several types of functions related risk to different independent variables, both deterministic and stochastic, using rigid and unrealistic underlying assumptions.

Asked whether nonuse of hired labour was a problem in estimating the production function, the author replied that all farmers had to use hired labour.

Another question related to the possible inefficiency of the estimates of supply response due to the nonuse of time-series data.

Participants in the discussion included G.D. Thompson.