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ALLOCATION OF FERTILIZER AMONG CROPS UNDER RISK— A QUADRATIC PROGRAMMING APPROACH

Farming in India is full of risk and uncertainty. The main sources of risk and uncertainty prevailing in crop and livestock production are output, price and yield instability. The main factors responsible for price fluctuations are unstable national and international commodity prices and shifts in government policies. Yield variability is caused by weather fluctuations and diseases. In such conditions, producers do not only aim to maximize income but also to reduce the risk. The measure of risk, affecting a producer, is the variability of income. Various models have been formulated to help producers in decision-making under risk and uncertainty. But there are only a few applications of these models to problems facing Indian agriculture. In this study, an E-V model (see Markowitz) has been used to consider the impact of price uncertainty on land and fertilizer allocations among crops in Punjab State. The regional decision problems are solved using quadratic programming. They result in an E-V frontier that shows the trade-off between the expected income and the standard deviation/variance of the income. The efficiency frontier corresponds to a number of alternative policies, each of them reflecting a different risk aversion level of the policy makers.

OBJECTIVES

The main objectives of the study are as follows: (1) to determine the optimal land and nitrogen fertilizer allocation with and without risk situations in Punjab State; (2) to derive the E-V frontier or the trade-off between expected return and risk in Punjab State; and (3) to evaluate the existing land allocation efficiency.

THEORETICAL APPROACH

For the study, both linear programming and quadratic risk programming models were used. Both models are discussed separately.

Linear Programming Model

The linear programming model (LP) was used as the analytical tool to determine the optimal cropping plan assuming risk neutrality. The following is the LP model:

$$\text{Max } Z = C'X$$

subject to

$$AX \leqslant B$$

and

$$X \geqslant 0$$

where

C = vector of expected revenue for the various crop activities,
X = vector of crop activities,
A = matrix of input coefficients relating the various crop activities with the different resources,
B = vector of resource constraints.

Examination of the LP objective function shows that the basic model does not account for risk and uncertainty in decision-making. Solutions are based on the expected revenues.

Quadratic Risk Programming Model

The revenue, say R_i per unit of X_i crop activity is assumed to be stochastic in nature and follows a normal distribution with mean C_i and variance σ_i^2. It is further assumed that the revenue R_i of each crop activity has an associated utility:

$$U(R_i) = 1 - e^{-\phi R_i}$$

where ϕ = risk aversion coefficient of the farmer.

According to Freund, as revenue at each point of time is normally distributed, the expected utility of revenue is maximized if one is maximized:

$$E(R_i) - \frac{1}{2} \phi \sigma_i^2$$

or

$$C_i - \frac{1}{2} \phi \sigma_i^2$$

R_i is random in nature, therefore

$E(R_i)$ is equal to C_i.

Now if revenue of each crop activity $X_1, X_2, \ldots\ldots\ldots\ldots X_n$ follows normal distribution with mean revenue $C_1, C_2, \ldots\ldots\ldots C_n$ and variance of revenue $\sigma_1^2, \sigma_2^2, \ldots\ldots\ldots\sigma_n^2$ respectively and covariance between two activities is σ_{ij}^2, the maximization of total expected utility of revenue is achieved by maximizing:

$$C'X - \tfrac{1}{2}\,\phi\, X'VX$$

Subject to:

$$AX \leqslant B$$

where,

$C' = (C_1, C_2, \ldots\ldots\ldots C_n)$

$V =$ variance-covariance matrix.

The problem is to choose $X \geqslant 0$ which maximize $C'X - \frac{1}{2}\phi X'VX$ subject to $AX \leqslant B$ with the help of programming considering the different values of a risk aversion coefficient. For the different values of risk aversion coefficient the optimal cropping plans are derived. The quadratic programming model gives the same outcome as the linear programming model when ϕ, the risk aversion coefficient, is zero. For a risk avertor, the value of ϕ is positive whereas for a risk lover the value of ϕ is negative. If the value of the risk aversion coefficient is large, the farmer is more conservative and the quadratic programming solution will give only small income as the low level of production activities will be activated, and most of the resources will be idle.

PROCEDURES AND DATA

The Punjab State has been selected for this study because the consumption of fertilizer per unit area also is comparatively high in this State. The principal *kharif* crops, *viz.*, paddy, jowar, bajra, pulses, groundnut and cotton, *rabi* crops, such as wheat, gram, pulses and oilseeds and annual crops, such as sugarcane, have been considered for the present study.

Input-Output Data

The latest data on response to nitrogen fertilizer for various crops for the years 1974-75, 1975-76 and 1976-77, were available from the agronomic experiments conducted at different research stations in the State. The average input-output crop yield response to different levels of nitrogen fertilizer for high-yielding and local varieties under irrigated and non-irrigated conditions were worked out separately. In this study, these input-output data were used.

Objective Function

In the objective function, the expected gross revenue of each crop activity per hectare was used as coefficients for the crop activities. The total yield per hectare of crop activities was converted into gross revenue per hectare for each year, using the farm harvest prices of crops for the period from 1965-66 to 1976-77. Thus, the total gross revenue for each activity for each year was calculated. To remove the inflation, the total revenue for each activity was deflated by price index using 1976-77 as the base year. After doing this exercise, we estimated the mean revenue for each activity which is random in nature and worked out the variance-covariance matrix of revenue. These expected revenue and the variance-covariance matrix have been used in the quadratic programming objective function.

The following constraints were used in the model:

Land constraints: For the Punjab State, the data on total net cultivated area and irrigated area of land for the reference year were taken from Indian Agricultural Statistics, 1975-76 and 1976-77. The total net available area of land in *kharif* and *rabi* season was classified into irrigated and unirrigated area. Time-series data on area under individual crops for the last ten years, *i.e.*, from 1966-67 to 1976-77 in the State were used to work out the individual crop area flexibility constraints for the programming model. These data were collected from Estimates of Area and Production of Principal Crops in India, for a period of ten years.

The consumption of nitrogen fertilizer nutrient in the year 1979-80 was used as the availability of nitrogen fertilizer nutrient.

Crop area flexibility constraints: Maximum and minimum crop area flexibility constraints for individual crops were imposed to keep the reservation regarding the expansion of area under certain crops. The procedure to estimate the flexibility coefficients was based on the yearly change in crop area during the past. The percentage change in the area of an individual crop over that in the preceding year was calculated for each year from 1966-67 to 1976-77. The highest value of percentage increase in the crop area over the preceding year was selected for working out the maximum crop area constraint. Similarly, the highest value of percentage decrease in crop area over the preceding year was used to work out the minimum crop area constraint.

Irrigated Crop Area Flexibility Constraints

The minimum irrigated crop area flexibility constraints were also imposed for the major irrigated crops of the State in the model so that the farmer is assured to get at least some returns from the irrigated crops. The existing proportion of irrigated area of a crop to the total cropped area was used to work out the minimum irrigated crop area flexibility constraint for individual crops. The minimum irrigated crop area constraint was calculated as the proportion of the lower limit of total crop area constraints for each crop.

RESULTS AND DISCUSSION

The optimal cropping plan for Punjab State was worked out with the linear programming technique without risk. A quadratic risk programming model was used to determine the optimal combinations of crops for the State. As stated earlier, the variance-covariance matrix of income has been used in the objective function, and the risk aversion coefficient was also included in the function. The measurement of the risk aversion coefficient is a purely subjective phenomenon. Moreover, its value depends on the level of wealth of the entrepreneur. According to Arrow, the measure of relative risk (Rr) aversion, Rr, is:

$Rr = \phi w$ (approximately equal to one)

where ϕ is the risk aversion coefficient, and w is the wealth which is equal to y/r, the ratio of income and rate of interest. If the mean value of income is $\bar{y}$, the wealth will be equal to $\bar{y}/r$, and from the above relation we can get

$$\phi = \frac{1}{\bar{y}/r}$$

Though the estimation of risk aversion coefficient is a purely subjective phenomenon, yet in this study an approximate value of risk aversion coefficient for the society as a whole in the State was worked out by considering $\bar{y}$ (the total gross revenue obtained under the risk neutral cropping plan of the State). The various values of ϕ, risk aversion coefficient, were worked out at different rate of interest.

For the sake of comparison the derived optimal cropping pattern was presented in Table I along with the risk neutral plan. A comparison of the

TABLE I—COMPARATIVE OPTIMAL CROPPING PATTERN WITHOUT RISK AND WITH RISK

Crop activity	Area (thousand hectares)	
	Without risk	With risk $\phi = 1 \times 10^{-9}$
Paddy, 80N	801·4	801·4
Maize, 60N	643·5	643·5
Bajra, 80N	185·7	—
Bajra, 0N	32·5	217·8 (15N)
Groundnut, 10N	186·0	186·0
Grain, 20N	500·5	500·5
Cotton, 40N	665·6	665·6
Oilseed, 20N	102·4	102·4
Wheat, 100N	2,981·3	2,425·5
Sugarcane, 85N	176·0	176·0
Wheat, 120N	—	555·8
Return (Rs. 10^6)	28,835	23,858

optimal cropping plan with and without risk revealed that there is no significant change in the plan. But even though it shows that the high fertilizer crop activities having high risk (such as bajra which has very high variance) had gone out of the plan, the lower level of fertilizer activity, of bajra, entered in the solution. Those activities such as wheat, using high levels of fertilizer and having comparatively lower variance, were in the plan. The results show that the total revenue in the developed plan under risk situation was reduced by 17.3 per cent.

The optimal allocation of nitrogen fertilizer among the various crops under risk and without risk situation is given in Table II. It may be seen from the table that in both the plans the maximum quantity of nitrogen

TABLE II—OPTIMAL ALLOCATION OF NITROGEN FERTILIZER AMONG VARIOUS CROPS UNDER NO RISK AND RISK PROGRAMME

Crop	Nitrogen (thousand kilograms)	
	No risk programme	Risk programme
Paddy	64,112	64,112
Maize	38,610	38,610
Bajra	14,856	3,476
Groundnut	1,860	1,860
Grain	10,010	10,010
Cotton	26,624	26,624
Oilseed	2,048	2,048
Wheat	298,130	309,510
Sugarcane	14,960	14,960

fertilizer nutrient was allocated to wheat, followed by paddy and maize. A comparison of the risk with risk-neutral programmes revealed that the high level of nitrogen fertilizer crop activity had gone out of the plan due to the high risk associated with fertilizer application. For instance, bajra, which required only 80 kg. of nitrogen fertilizer per hectare without risk required only 15 kg. of nitrogen fertilizer per hectare with risk. Other crops, such as wheat, which have low risk used higher levels of fertilizer. This implies that the risky crops do not utilize high levels of fertilizer.

Expected returns, standard deviations, and coefficients of variation at various levels of risk aversion coefficients are presented in Table III. It may be seen from the results in this table that high risk aversion coefficients reduced the expected return due to the inclusion of low fertilizer crop activities in the solution. At low levels of expected income, the standard deviation is also low, of the order of Rs. 3.16×10^9.

TABLE III—INCOME AND RISK TRADE-OFF WITH ASSOCIATED OPTIMAL FERTILIZER-CROP COMBINATION AT VARIOUS LEVELS OF RISK AVERSION COEFFICIENT, ϕ

Risk aversion coefficient, ϕ	Expected return (Rs. 10^6)	Standard deviation of return (Rs. 10^9)	Coefficient of variation
1×10^{-10}	28,335	3·16	11·1
1×10^{-9}	23,858	2·80	11·7
2×10^{-9}	19,200	1·67	8·7
5×10^{-9}	10,554	1·13	10·7
Actual	20,692	2·41	11·6

The total income from the existing crop area allocation resulting from actual fertilizer applications using the experimental input-output relations, was worked out The associated variance was also worked out. The value of expected income corresponding to a risk aversion coefficient was within the range of 1×10^{-9} to 2×10^{-9} (Table III). This implies that the actual risk aversion coefficient[1] lies within this range. If we compare the return at the risk aversion coefficient, 1×10^{-9}, the actual return is reduced by 13 per cent.

CONCLUSIONS

The results of this study lead to two important conclusions that seem to have relevance for policy implications. First, the risk caused by price instability resulting in variation in the income from the crop affected the allocation of land and fertilizer among the crops. Low risk crops associated with low levels of fertilizer were in the optimal cropping plan in place of high risk crops. Appropriate price and crop insurance policies should be implemented in order to stabilise income. Secondly, the existing land and fertilizer allocation pattern is away from the efficient E-V frontier. It implies that the existing cropping plan is inefficient in the sense of minimum risk portfolio.

Chhotan Singh and David Zilberman*

1. Generally, the theory of decision-making under uncertainty was developed to explain the behaviour of individual farmers. This study analyses the behaviour of a macro-economy, and the implied measures of risk aversion may reflect policy makers' choice or some sort of 'social' risk preferences.

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AN ESTIMATE OF DEMAND FOR AND SUPPLY OF CEREALS, COARSE GRAINS, PULSES AND OILSEEDS IN HARYANA

Economic growth gives rise to a number of forces leading to a rapid increase in the demand for foodgrains. These forces many a time raise difficult problems if the supply is not adequate. Ensuring a balance between the demand for and supply of foodgrains, therefore, is one of the important tasks of the government or the planning authority in a developing economy. However, it is not merely the overall balance between the demand for and the supply of foodgrains which is important in the context of a developing economy. Equally important is the balance between the demand for a particular foodgrain and its supply.[1]

Empirical prediction of agricultural supply is a difficult task because there are millions of farmers on whose decisions and actions production depends, but more so due to risk and uncertainty involved in changing agriculture. The task becomes more difficult because of the complex structure of agriculture constantly being affected by the impact of technology, structural changes, improvements, aggregation and non-availability of appropriate data. In a relatively younger State like Haryana, it is all the more difficult to make with precision the predictions about supplies. Therefore, in the present study an attempt has been made to project the demand for and the supply of cereals, coarse grains, pulses and oilseeds in Haryana by 1986-87.

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