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RISK MANAGEMENT IN DIFFERENT FARM SITUATIONS: AN APPLICATION OF GAME THEORY

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Methodologies for handling risk at the individual farm level are well developed in the literature for a wide range of decision criteria and attempts have already been made to quantify the risk and uncertainty through the use of linear and quadratic programming. Hazell (1970), Rae (1971) and Maruyama (1972) concentrated on the investigation of trade-off between expected and the worst possible functional values, instead of being content with finding a single 'optimum programme' and these approaches constitute a parametric extension of earlier attempts based on constrained game. More general solution in this approach is to assume that the multivariate joint probability distribution of the elements of the stochastic constraint is discrete and the solution can be obtained either through a game theoretic approach or by using the active discrete stochastic programming approach developed by Cocks (1968) and extended by Rae (1971). The game theoretic approach has the advantage of being solved relatively easily and the result can be derived for varied risk levels with the available linear programming package. An alternative method of solving sequential stochastic progamming problem of the type originally outlined by Cocks (1968), Rae (1971) and Hazell (1970) is developed in the present study to derive sets of alternative farm plans under varied risk levels in different farm situations to discuss the risk management mechanisms that could be suggested for different farm situations.

THE MODEL

While incorporating risk in the model all the competitive forces and uncertainty facing a farmer can be summarised as a composite nature component. Nature can then be considered as an opponent in a two-person zero sum game, which plays against a farmer in his selection of farm plans. The farmers' strategies are the possible farm enterprises. The state of nature can be defined as a set of actual prices and yields obtained for each number of years. Pay-offs are measured in enterprise returns net of all variable costs and this is inferred as gross margin. Thus, the model is concerned with the household decisions about which crops to grow to maximise the net income of the farm.

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In evaluating a particular farm plan, the farmer is assumed to be interested in two characteristic variables; the average net income $\bar{B}$ that would be realised over a number of years in a given farm plan and V, the minimum net income that would be realised in a bad year. V can therefore be viewed as a measure of security, while $\bar{B}$ measures the average income of the farm. Both $\bar{B}$ and V depend on the choice of crop activities, and the selection of a particular plan will depend on the relative weights the farmer assigns to each of these variables.

The minimum liquidity V that is maximised in the model represents the farmer's net income.

The structure of the model is

Max V

Subject to

$$\sum_t PR_t \, INC_{st} \geqslant \lambda$$

where INC_{st} denotes net income in t th year (state of nature), PR_t is the probability of similar years to the t th occurring, and λ is a scaler to total gross margin of the farm. Alternative farm plans are generated by varying the value of λ entered in the model from zero to unbounded to derive farm plans under varied risk level.

The state of nature is introduced in the model by analysing the historic data on prices and yields of major crops. In the present model, the state of nature was limited to two years since positive correlation of revenue of various crops are observed in the district.[1] The two years selected are 1980-81 and 1981-82, since in 1980-81 the annual rainfall was 416.2 mm. which was 57 per cent less than the normal rainfall. Hence this year was taken to represent the bad year. In 1981-82 the annual rainfall was 962.99 mm. which was the same as the normal rainfall (960.50 mm.) and this year was taken to represent the normal year.

The probability of occurrence of bad year was estimated by analysing annual rainfall data of 33 years and their deviation from normal rainfall. The analysis showed that both excess rainfall and normal rainfall were observed only in 11 years, whereas severe drought was observed in three years, mild drought and moderate drought were experienced in 9 and 10 years respectively. Since the moderate and severe drought occurred for 13 of the 33 years, the probability of occurrence of bad year was taken as 0.40 and normal year as 0.60 in the study area.[2]

1. If the revenues of different crops move together over time (they are positively correlated), then many years' data need not be included in the model as their variations among the years will be less.

2. The mild drought refers to a situation when the rainfall in a particular year is deficient by 11 to 25 per cent from the annual rainfall. If the deficiency from the normal rainfall is in the range of 26 to 50 per cent, the drought is considered moderate. If the deficiency is above 50 per cent, it is considered as severe drought. For further details, please see Goverment of India: Report of the National Commission on Agriculture 1976, Part IV: Climate and Agriculture, Ministry of Agriculture and Irrigation, New Delhi, 1976.

Since the measure of security is introduced into the model to measure the risk, the objective function is to maximise the minimum income of the farm. The choice of crop activities for the initial programme was based on technical feasibility, managerial skill and the farmers' preference as observed during the survey. The crop activities were differentiated for two different seasons, namely, first season (June to October) and second season (November to May). Other activities such as labour hiring activities, borrowing activities, family living expenses activities and cash transfer activities were also introduced in the model. Restricted availability of land, labour and purchased input resources are incorporated in the model as constraints.

Income of farms for different seasons, s, and different states of nature, t, is specified as income identity which is explained by the difference between the total income for crop activities, for different s, t and the total cost for different s, t. Similarly, the cost for different s, t is represented by the total sum of expenditure on wages, fertilisers, pesticides, water and cost of credit. The cash balance for each season is represented by the sum of last season cash balance and net income which is derived by subtracting consumption expenditure, cost of production and credit from total income.

Since credit is the major external source of finance, it is specified as a separate constraint. The credit supply for different seasons in each state of nature must be equal to the cost for each season less the balance of income from previous season for each state of nature. Since the consumption for different s, t is the function of income of respective s, t plus a fixed level of autonomous (subsistence) consumption, the consumption function is estimated for different situations and the coefficients are used in the model.

DESIGN OF THE STUDY

Four different farm situations representing irrigated and semi-irrigated small and large farms were identified from the 100 randomly selected sample farms in Alathur block of Tiruchirapalli district in Tamil Nadu. The representaive farms selected for the study from the sample farms have the size, resource availability and cropping pattern approximately equal to the average situation of the sample farms of each situation. Cross-section data were collected for the years 1980-81 and 1981-82 representing two states of nature to measure the risk behaviour in farming. The study has also covered the time-series data for 15 years since 1968 on prices and yield for various crops from published sources.

RESULTS AND DISCUSSION

The average size of irrigated farms was 1.29 hectare and that of small and large farms was 0.57 hectare and 1.68 hectare respectively. In the case of semi-irrigated farms the average farm size was 1.99 hectare, and that of small and large farms was 0.87 hectare and 2.56 hectares respectively. The entire area under irrigated situation had the benefit of irrigation, while in the semi-irrigated situation, only 47.60 per cent of the area had assured irrigation. Among the size-groups, the percentage of area under irrigation was more on large farms (53.03 per cent) than on the small farms (36.74 per cent).

Since the objective function results of the model indicate the maximised) minimum income (Max.V or maximin) and average income [Max. E (INC)] of the given plan, the risk level of farms could be measured by comparing the increase in the average income and the reduction in the minimum income between maximin and Max. E (INC) solution. The results of the average and minimum income derived through the model in different farm situations are presented in Table I.

TABLE I. MINIMUM AND AVERAGE NET INCOME IN DIFFERENT FARM SITUATIONS

(*Rs. per farm*)

Sr. No.	Particulars	Irrigated				Semi-irrigated			
		Small farms		Large farms		Small farms		Large farms	
		Max.V	Max.E (INC)	Max.V	Max.E (INC)	Max. V	Max.E (INC)	Max.V	Max.E. (INC)
1.	Average net income ..	2,225	3,037	2,808	3,374	2,284	2,335	5,381	6,974
2.	Minimum net income	1,168	2,290	2,703	3,106	2,233	2,294	4,373	5,934
3.	Net income (bad year)	1,168	1,168	2,703	2,703	2,233	2,233	4,373	4,373
4.	Net income (normal year)	2,930	3,037	2,878	3,374	2,335	2,335	6,053	6,974

It may be noted from the table that the average net income was maximum in semi-irrigated large farms [Rs. 5,381 under maximin and Rs. 6,974 under Max. E (INC)] followed by irrigated large farms [Rs. 2,808 under maximin and Rs. 3,374 under Max. E (INC)]. Among the small farms it was more in irrigated situation [Rs. 3,037 under Max. E (INC)] than in semi-irrigated situation [Rs. 2,335 under Max. E (INC)]. The net income under maximin solution for the small farms of irrigated and semi-irrigated situation was almost the same. The maximised minimum income was more on the large farms than on the small farms in both the irrigated and semi-irrigated situations.

The increase in average income and reduction in maximised minimum income of the normative plans derived through this model have shown that the average income of the irrigated and the semi-irrigated small farms is raised only by Rs. 812 and Rs. 51 respectively whereas the minimum income is reduced by Rs. 1,122 and Rs. 61 for the above situations respectively between maximin and Max. E (INC) solutions. Hence it is plausible to assume that risk is more in the case of small farms than on the large farms both in the irrigated and semi-irrigated situations.

This behaviour of farm plans towards risk situations could be explained by the ratio of difference between average income and maximised minimum income of maximin and Max. E (INC) solutions. The estimated ratios are presented in Table II.

TABLE II. INCREASE IN AVERAGE NET INCOME AND REDUCTION IN MINIMUM NET INCOME IN DIFFERENT FARM SITUATIONS

(*Rs. per farm*)

Sr. No.	Particulars	Irrigated		Semi-irrigated	
		Small farms	Large farms	Small farms	Large farms
1.	Increase in average net income in Max. E (INC) over Max.V	812	566	51	1,593
2.	Decrease in minimum net income in Max.E (INC) over Max. V	1,122	403	61	1,561
3.	Ratio (1÷2)	0·73	1·40	0·84	1·02

The ratio of more than one indicates the less risky nature of the farm plans. The table revealed that the ratio was more than one on the large farms of both the irrigated and semi-irrigated situations whereas it was less than one on the small farms. Among the irrigated and semi-irrigated situations, the ratio was more in the irrigated situation than in the semi-irrigated situation. This might be due to less assured irrigation potential in the semi-irrigated situation than in the irrigated situation, which increases the instability in farming. Even among the small farms, the ratio was less in the irrigated farms than in the semi-irrigated farms. A possible reason for this trend could be due to smaller farm size in the irrigated situation than in the semi-irrigated situation, which limits the net income of the farm.

The efficiency of the normative plans are evaluated by its comparison with the existing plans and the results are presented in Table III.

TABLE III. NET INCOME OF DIFFERENT FARM SITUATIONS—EXISTING AND NORMATIVE PLANS

(*Rs. per farm*)

S. No.	Particulars	Irrigated		Semi-irrigated	
		Small farms	Large farms	Small farms	Large farms
1.	Existing plan	873	2,832	1,932	5,269
2.	Normative plans				
	Max.V	1,168	2,703	2,233	4,373
	Max.E (INC)	2,290	3,106	2,294	5,934

The results in Table III show that the net income of the existing plan is less than that of Max. E (INC) in all the situations, which indicates the scope for improving the income by adopting the suggested normative plans. Surprisingly, the net income of the existing plan was less than the maximin solution in all the small farm situations. This explains that the scope for increasing net income by optimising the farm plan under risk situation is more on the small farms than on the large farms. Hence the small farmers may be advised to adopt the maximin solution under risk situation and Max. E (INC) under normal situation.

A critical analysis of the cropping pattern of normative plans and its comparison with the existing plan would provide an understanding about the risk adjustment mechanism in different farm situations. The cropping pattern and cropping intensity suggested by the normative plans with the existing farm plans are presented in Table IV.

TABLE IV. CROPPING PATTERN UNDER EXISTING AND NORMATIVE PLANS IN DIFFERENT FARM SITUATIONS

(*hectares*)

Sr. No.	Crops	Irrigated					
		Small farms			Large farms		
		Existing plan	Max. V	Max.E (INC)	Existing plan	Max. V	Max. E (INC)
I.	Irrigated						
	1. First season						
	Paddy	0·42	0·02	0·02	1·16	0·40	0·40
	Onion	0·04	—	—	0·18	0·21	—
	Chillies	0·10	0·18	0·13	0·32	—	1·14
	Vegetables	0·01	0·13	0·17	0·02	0·02	0·08
	2. Second season						
	Groundnut	0·27	0·57	0·57	0·84	1·02	1·62
	Cumbu	0·13	—	—	0·17	—	—
	Cholam	0·11	—	—	0·47	0·60	—
	Gingelly	0·05	—	—	0·06	—	—
II.	Rainfed						
	Groundnut	—	—	—	—	—	—
	Coriander	—	—	—	—	—	—
	Cholam	—	—	—	—	—	—
	Varagu	—	—	—	—	—	—
	Gingelly	—	—	—	—	—	—
	Chillies	—	—	—	—	—	—
	Cotton	—	—	—	—	—	—
III.	Total cropped area	1·13	0·90	0·89	3·22	2·25	3·24
IV.	Cropping intensity	198	158	156	192	134	193

(*Contd.*)

TABLE IV (*Concld.*)

(*hectares*)

Sr. No.	Crops	Semi-irrigated					
		Small farms			Large farms		
		Existing plan	Max.V	Max.E. (INC)	Existing plan	Max. V.	Max. E. (INC)
I.	Irrigated						
1.	First season						
	Paddy	0·26	0·03	0·03	0·75	0·51	0·41
	Onion	0·04	0·32	0·22	0·12	—	0·68
	Chillies	0·06	0·05	0·04	0·44	0·16	0·42
	Vegetables	—	—	—	—	—	—
2.	Second season						
	Groundnut	0·25	0·40	0·40	0·62	1·62	0·91
	Cumbu	0·05	—	—	0·23	—	—
	Cholam	0·04	—	—	0·20	—	—
	Gingelly	0·03	—	—	0·07	—	—
II.	Rainfed						
	Groundnut	0·18	—	0·02	0·20	0·91	1·18
	Coriander	0·17	—	—	0·52	—	—
	Cholam	0·12	—	—	0·15	—	—
	Varagu	0·06	—	—	0·10	—	—
	Gingelly	0·03	—	—	—	—	—
	Chillies	0·04	0·51	0·51	0·04	—	—
	Cotton	0·04	—	—	0·20	—	—
III.	Total cropped area	1·37	1·31	1·22	3·64	3·20	3·60
IV.	Cropping intensity	157	151	140	142	125	141

Though the existing plans have many crops in each of the seasons, the normative plans have selected the efficient crop-mix for various risk levels. The comparison of existing and normative plans show that the area under paddy and onion is replaced by chillies and vegetables in the irrigated and semi-irrigated small farms because of their low value products. Under maximin solution, the risk is managed by reducing the area under chillies which is compensated by vegetable crops. In the second season, the entire area is recommended for groundnut crop. Though the production expenditure of the groundnut is relatively higher than that of the other crops during this season, this crop is recommended and this might be due to higher net cash balance available from the first season.

An interesting observation here is that more of capital intensive crops is introduced in the normative plans by replacing less remunerative crops like paddy, *cholam* (great millet), etc. This is possible because the model allowed unrestricted credit. In other words, probably because of limited cash availability, the farmers are adopting the existing plan which is inefficient. Hence if the farmers are provided with adequate credit, then they can adopt the normative plans and they can be helped to maximise their incomes.

In the case of irrigated large farms, a similar shift in the cropping pattern as on the small farms is observed; however, under risk condition the plan suggests to reduce the area under chillies which is replaced by onion crop. Under maximin solution, in the semi-irrigated large farms, the first season area is reduced by 44 per cent of the cropped area of Max. E (INC) solution. This might be due to the reduction in the profitability of crops during the bad year due to inadequate water supply.

The cropping intensity is the same both in the normative plans and in the existing plans on the large farms in both the irrigated and semi-irrigated situations. However, it is less by 30 per cent and by 17 per cent on both the irrigated and semi-irrigated small farms respectively. These results show that the small farms have the scope for reducing the area under cultivation and instead they can raise more commercial crops to increase the net income of the farm.

Since unrestricted credit limit was allowed in this model, the derived normative plan suggests the maximum credit limit for different farm situations. The maximum credit limit is used by the large farms in the semi-irrigated situation (Rs. 8,553 in normal year and Rs. 4,030 in bad year) followed by the irrigated situation (Rs. 6,311 in normal year and Rs. 3,327 in bad year) (Table V). The maximum credit limit under different risk situations has shown that it was more in maximin than in Max. E (INC) solution on the small farms in the irrigated and semi-irrigated situations. This may be due to the fact that the farmers avail of more credit to manage the risk situation when their source of self-finance is limited.

TABLE V. MAXIMUM CREDIT LIMIT FOR THE NORMATIVE PLANS IN DIFFERENT FARM SITUATIONS

(*Rs.*)

Sr. No.	Particulars	Irrigated				Semi-irrigated			
		Small farms		Large farms		Small farms		Large farms	
		Max.V	Max.E (INC)	Max.V	Max.E (INC)	Max.V	Max.E (INC)	Max.V	Max.E (INC)
1.	Bad year	867	987	1,760	3,327	713	1,015	3,160	4,030
2.	Normal year	1,010	1,647	3,170	6,311	1,120	1,970	5,410	8,553

CONCLUSION

The foregoing analysis has clearly indicated that there is a more unfavourable trade-off between risk and net income on small farms in both the irrigated and semi-irrigated situations than on the large farms. Hence the large farms may be advised to adopt the maximin solution under risk situation and Max. E (INC) solution under normal situation. Since the risk is observed to be more on the small farms, they should be advised to adhere to the more conservative strategies implicit in the maximin solution.

The normative plans derived through this model indicate that there is scope to improve the efficiency of the existing plan by changing the cropping pattern. Further, the above analysis indicates that restricted credit had resulted in greater reduction in net income under risk condition than under the normal situation and the restricted credit resulted in a shift from commercial crops to food crops in all the situations. This conclusion calls for effective credit policy which is more essential under risky situation than under the normal conditions.

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