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Evaluating Agricultural Energy Policies Under Uncertainty: The Case of Electricity in South India

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Abstract

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Farmers' attitude towards risk associated with the availability of energy inputs will influence their investment behavior and demand for energy inputs. In order to analyze policies that reduce the risk in energy availability, some modifications in methods are required. This study, using a mean-variance framework, demonstrates how cross-sectional data and time-series data on crop yields and prices can be used to analyze agricultural energy policies under uncertainty in a developing country context. It is argued that the farmers risk attitudes, their crop allocation behavior, changes in the demand for energy inputs and the stochastic relationship between various forms of energy inputs can be explained by the various energy constraints faced by them. Furthermore, using the same methods the impact of policies which affect these constraints, can be analyzed.

1. Introduction

Crop production in many developing countries is associated with a high degree of randomness due to uncertain availability of energy inputs, accentuated by the vagaries of monsoons. Electrical energy for irrigation in cotton farms of the Coimbatore region in Tamil Nadu, India is typical. Modifications of usual procedures are required in analyzing the production structure of such farms and formulating the policy options when this uncertainty is introduced.

In studying farmers' behavior under uncertainty, various alternative paradigms have been developed and empirically tested for their adequacy and usefulness. The expected utility hypothesis has been used to order action choices with uncertain outcomes according to an expected utility index, when known utility functions represent the risk preferences of the farmers.

Freund (1956) and Markowitz (1959) presented the expected utility hy-

pothesis in a programming framework. Hazell (1971), Hazell and Scandizzo (1974) and Paris (1979) are among a large number of studies which have developed variants of risk-programming models depending on the utility functions used and uncertainty of coefficients involved.

Several empirical investigations have also been made using these models in selecting optimal crop mix and in testing the behavioral assumptions of farmers towards risk (Hazell, 1971, Thomas et al., 1972, Brink and McCarl, 1978, Gebremeskel and Shumway, 1979, Mapp et al., 1979, Kliebenstein and McCamley, 1982; Lambert and McCarl, 1985).

Binswanger (1980, 1981), using an experimental gambling approach to study the attitude towards risk of semi-arid farmers of India, concluded that wealth does not influence risk aversion significantly at higher pay-off levels and that the differences in investment behavior among farmers could not be explained by their risk attitudes but must be explained by differences in their constraint sets. Recently, Grisley and Kellogg (1987) arrived at similar conclusions from a sample of Thai farmers.

However, there exists very little systematic information for understanding the risk-taking preferences of farmers towards energy inputs. It is not clear how a farmer subjected to an uncertain availability of energy inputs would react to various policy alternatives of the government, since policies could affect the energy constraints faced by him. Also very little is known about how energy marginally affects risk in crop production and the stochastic relationship (complements or substitutes) between various forms of energy inputs.

The purposes of this paper are threefold. The first is to study the allocative behavior of various groups of farmers with differing resource bases, who face uncertainty in the availability of energy inputs. The second purpose is to evaluate the effects of policies that improve the availability of energy on cropping patterns and energy demands, and finally to analyze the stochastic relationship between energy inputs in crop production. A general description of the study area, data and the theoretical model used is given in Section 2. Results of the analysis are presented and discussed in Section 3. Summary and conclusions form the last section.

2. Study area, data and the model

The analysis presented in this paper uses data from the Sarkar Samakulam Block of eight villages in Coimbatore district of Tamil Nadu, India. The block is characterized by black soil suitable for growing irrigated cotton. Since the water table of the wells in the study area is 200 m on average below the ground level, irrigation is totally dependent on the availability of electrical energy. It should be noted that it is not uncommon in many parts of India for the farmers to keep oil engines to circumvent the uncertainty in the availability of electri-

cal energy. However, the ownership data collected from the study area (Appendix table A1) show that only 16% of large farmers, 8% of medium farmers and 6% of small farmers owned both oil engines and electrical engines and none of the farmers owned just the oil engine to pump water from the well. This could be due to the fact that the use of electrical energy for agricultural purposes is highly subsidized by the state government. The diesel fuel for oil engines is not subsidized since it can be used for other purposes such as running tractors and power tillers and cannot be monitored effectively. Thus for the farmers in the study region, the availability of electrical energy is an important determinant of crop yields and farm revenue.

A major problem in crop production observed in the study area is the discontinuous supply of electricity which increases the cost of cultivation due to improper management associated with irrigating the crop fields and may result in poorer crop yields. This can be seen from the fact that the variability of crop yields is highly associated with the variability in the supply of electrical energy when compared to other factors in the study area (Appendix table A2). This is also supported by the results of a subjective interview on the major determinants of crop yields in the study area with the farmers, agricultural officers and agricultural engineers in the study area (Babu and Rajasekaran, 1987). While the variability in the crop yields could also result from the factors such as variability in the fertilizer use and uncertainty in the incidence of pests and disease, it is reasonable for the study area to assume that the stochasticity in crop yields in these farms is dependent on the availability of electrical energy for well irrigation. Since the crop prices are announced by the Agricultural Price Commission before each crop season, there is little variability in crop prices and hence the stochasticity in farm returns can be assumed to be dependent on electrical energy supply. Hence the stochasticity in farm returns in these farm comes from yield uncertainty which is dependent on the availability of electrical energy for well irrigation.

Data

This study considers four major forms of energy, namely human energy, animal energy, mechanical energy, and electrical energy. The data on the energy requirements, profitability, energy productivity and the cost of the energy for various crops was obtained from a survey conducted in the block on 120 farms of various sizes that were randomly selected during the first 3 months of 1985. The supply of electrical energy to various villages during different months of the year was collected from the regional electricity office located in the block. The data have earlier been used in Babu and Rajasekaran (1987).

Farmers in the study area grow cotton, rice, sorghum and ragi (finger millet), forming about 77% of the total area cultivated. Cotton and rice require high amounts of irrigation and hence are subjected to a high degree of yield uncertainty while sorghum and ragi are less risky crops. This can be verified

TABLE 1

Variance-covariance matrix of expected net returns of crop enterprises

	Cotton	Rice	Sorghum	Ragi (finger millet)
Cotton	682.30	283.50	-123.30	-148.60
Rcie		821.60	-181.80	-162.90
Sorghum			352.20	123.40
Ragi				143.80

from comparing the significance of these inputs in the production of these crops. Subramanian (1986), analyzing the production functions of these crops in the study region, has argued that irrigation is the principal determinant of crop yields. Production function estimates using water and nitrogen as inputs are given in Appendix table A3.

The net expected returns from the above four crop enterprises were calculated using cross-sectional and time-series data on yield and market prices. The variance-covariance matrix of expected net returns calculated based on the cross sectional data is presented in Table 1¹. It can be seen from the table that growing cotton and rice seems to be highly risky while sorghum and ragi are associated with less risk. There exists a negative covariance between cash crops (cotton and rice) and the millets (sorghum and ragi) reflecting their competition for the limited resources of the farmers.

The Model

Uncertainty in farm returns can come from three different sources, namely input prices, output prices, and yield which is dependent on the water availability in the case of irrigated farming. In the present analysis the yield uncertainty arises from the uncertain availability of electrical energy.

Following are the behavioural assumptions made in the present analysis. The farmers are assumed to maximize the expected utility of net income with concave preferences. The distribution of the net income of the farmers is assumed to depend only on two parameters, namely the mean and the variance of the risky crop returns. While the limitations of mean variance analysis are well known (Meyer, 1987), the use of such models is common in the farm planning literature (Freund, 1956; Hazell, 1971; Norton and Solis, 1983).

¹The variance-covariance of the expected net returns calculated based on time series data on yield and output prices for the study area is given in Appendix table A4. This is also valid information that could be used in analysis of risk in farming (Hazell and Norton, 1986). Since similar results were obtained from both the times series variance-covariance and the one presented in Table 1, only the analysis based on the cross-sectional data is discussed in this paper.

If the vector of crop net returns say, X is distributed with mean M and variance-covariance matrix of S , the farm level optimization model can be written as:

$$\text{MAX } E[U(X)] = \text{MAX } J = M' C - (R/2) C' S C$$

subject to

$PC \leq Q$ energy input constraints

$C \geq 0$ non negativity constraint

where $E[U(X)]$ is the expected utility of net returns, C the $(n \times 1)$ vector of crop production activities, P the $(m \times n)$ matrix of energy requirement coefficients of crops used in constraints, Q the $(m \times 1)$ vector of energy availability, and R is the measure of risk aversion (Pratt, 1964; Arrow, 1965).

The above quadratic programming model is used to determine the optimal crop plan that is consistent with the observed behavior of the farmer by comparing the solutions of the model obtained under various degrees of risk aversion. The risk attitude of the farmer is approximated by the degree of risk aversion that yields the solution for the model that is similar to the actual behavior of the farmers (Hazell, 1982). Two scenarios, namely the existing electricity supply pattern (policy 1) and an increased electrical energy supply of 10% during the critical stages of crop growth (policy 2), are analyzed to observe the pattern of changes in risk attitudes of the farmers towards electrical energy supply. It should be noted that the existing supply pattern of electricity has inadequate supply combined with many interruptions during a single day which is the source of uncertainty (low mean supply with high variability). The scenario in policy 2 would reduce the uncertainty both by providing increased quantity of electricity and by supplying it during the preannounced timings during the months of crop season when irrigation is an important farm operation (higher mean supply with low variability). Thus a policy which provides higher quantity of electrical energy without assured timings may not reduce the variability in the supply of electrical energy. Using the results of the above analysis the stochastic relationship between various forms of energy inputs is studied by observing the changes in the land allocation pattern of farmers among the crops.

3. Results and discussion

The above model was repeatedly solved for various levels of the absolute risk aversion coefficients ($R=0.0-0.1$) and the farmer's risk aversion coefficient was taken to be that value of the parameterized coefficient which minimized the difference between the model results and the actual crop mix. The differ-

ence was measured in terms of the total absolute deviation in acreage of each of the four crops (cotton, rice, sorghum, ragi) and in terms of the summed total absolute deviation of all four crops (Hazell, 1971; Brink and McCarl, 1978).

A comparison of solutions of the model under the existing electricity supply pattern and a policy of 10% increase in the supply of electricity is presented for three types of farmers (defined based on land holding as: small farmer with less than 2 ha, medium farmer with 2–5 ha, and large farmer with more than 5 ha) in Table 2.

The farmers of the study area are not risk-neutral irrespective of their resource base. The model results show that the large, medium and small farmers had an absolute risk aversion level of 0.0006, 0.001 and 0.007, respectively. The degree of their risk aversion decreases with land holdings supporting the validity of the behavioral assumption of Decreasing Absolute Risk Aversion (DARA), that has widely been used in analysis of agricultural production under uncertainty.

TABLE 2

Crop allocations at various levels of risk aversion for three types of farmers under two policy scenarios^a (ha)

Farmer type and crops	Actual cropping area	Level of risk aversion (R)							
		Existing electricity supply (Policy 1)				10% Increased electricity supply (Policy 2)			
		0.00	0.0006	0.001	0.007	0.00	0.0006	0.001	0.007
Small									
Cotton	0.62 ^b	0.00	0.10	0.18	0.60	0.00	0.14	0.53	0.67
Rice	0.31	0.00	0.00	0.16	0.34	0.00	0.00	0.19	0.39
Sorghum	0.23	0.87	0.80	0.67	0.21	0.87	0.91	0.44	0.18
Ragi	0.19	0.48	0.45	0.34	0.20	0.48	0.30	0.19	0.11
Medium									
Cotton	1.27	0.49	0.95	1.28	1.42	0.49	1.01	1.34	1.55
Rice	0.98	0.47	0.72	1.00	1.07	0.47	0.75	1.00	1.12
Sorghum	0.72	1.40	1.16	0.66	0.67	1.40	1.11	0.70	0.45
Ragi	0.43	1.04	0.57	0.46	0.24	1.04	0.53	0.36	0.28
Large									
Cotton	2.08	0.96	2.10	1.83	1.57	1.02	2.20	1.85	1.56
Rice	2.17	1.28	2.10	2.10	2.05	1.53	2.31	2.91	2.64
Sorghum	0.94	2.04	0.99	1.16	1.24	1.80	0.78	1.09	1.60
Ragi	0.76	1.67	0.76	0.86	1.09	1.60	0.65	0.10	0.15

^aSeveral policy scenarios with varying levels of increased electricity were studied and only the results relevant for discussions are presented due to space considerations.

^bValues in italics indicate crop allocation at which model results are similar to actual cropping area.

The results on crop allocations due to increased and assured energy availability show that the farmers switch to risky cash crops namely cotton and rice from less risky crops namely sorghum and ragi at the same risk aversion level. This implies that any policy that reduces uncertainty in the availability of farm inputs, would increase the production of crops that use large amounts of these inputs.

The impact of the policy of increased supply of electricity on the demand for energy inputs is calculated based on the per-hectare energy requirement of crops determined from the farm survey data. The policy of increased electricity supply increases the demand for electrical energy as well as human energy at the same rate in all types of farms reflecting a strong complementarity between electrical and human energy inputs. However, the changes in demand for animal and mechanical energy inputs show a different picture. Small farmers increase their demand for animal energy to the same extent as that of electrical energy while their demand for mechanical energy remains unchanged. Medium and large farmers used more of mechanical energy compared to animal energy with the increased electricity supply.

The percentage increase in the energy demand due to the policy shows that the small farmers who are identified as the most risk-averse by the model use less than 10% of the increased electrical energy, while the medium farmers use almost all increased availability; the large farmers would use more than the available energy due to the policy. While this result is also consistent with the DARA hypothesis, it supports the view that electrical energy is a marginally risk-reducing input meaning that the risk-averse farmer would utilize a lesser quantity of electrical energy than if he is risk-neutral (Pope and Kramer, 1979) and that increasing the availability of electricity in the study area would reduce the yield uncertainty faced by the farmers. This was verified by comparing the above results with the demand changes in electrical energy assuming risk neutrality of the farmers ($R=0.00$ from table 2) for the same policy. The comparisons are presented in Table 3 under risk neutrality. It could be noted that if the farmers are not risk-averse to the uncertainty in the supply of electricity, then the policy of increased and assured supply of electricity does not influence the investment pattern in crops for small and medium farmers. Thus demand for energy inputs also does not show any change for these farmers. However, the large farmers would respond to the policy even if they are risk-neutral and increase the use of electricity, human labor, animal energy and mechanical energy. This is not surprising given the fact that the large farmer's risk aversion coefficient being closer to zero ($R=0.0006$) compared to smaller and medium farmers.

It is clear from the above results that farmers' reactions to government policies are largely influenced by their risk-taking preferences towards uncertain availability of energy inputs. Thus traditional methods of analyzing energy use in agriculture that do not consider the risk attitude of the farmers may not

TABLE 3

Impact of agricultural energy policy on demand for energy (MJ/ha)

Farmer type	Electrical energy	Human energy	Animal energy	Mechanical energy
Policy 1				
Small	2.30	0.67	0.15	0.29
Medium	5.91	1.73	0.40	0.59
Large	10.76	3.19	0.71	1.13
Policy 2				
Small	2.46 (6.96) ^a	0.72 (7.46)	0.16 (6.66)	0.29 (0.00)
Medium	6.50 (9.98)	1.97 (13.87)	0.41 (2.5)	0.61 (3.39)
Large	12.40 (15.24)	3.68 (15.36)	0.72 (1.41)	1.19 (5.31)
Under risk neutrality ($R=0.00$)				
Policy 1				
Small	2.41	0.42	0.11	0.21
Medium	6.10	1.61	0.31	0.52
Large	12.11	2.87	0.52	0.98
Policy 2				
Small	2.41 (0.00) ^a	0.42 (0.00)	0.11 (0.00)	0.21 (0.00)
Medium	6.10 (0.00)	1.61 (0.00)	0.31 (0.00)	0.52 (0.00)
Large	12.31 (1.65)	3.17 (19.87)	0.57 (9.61)	1.02 (4.08)

^aPercentage increase in demand due to Policy 2.

predict the true changes in the energy demands when farmers make decisions under uncertainty.

In evaluating policies that improve the availability of energy inputs or subsidize the use of certain other forms of energy such as fuel, it is important to understand the implications of these policies towards changes in cropping patterns and their impacts on the use of other forms of energy inputs. Given yield uncertainty, the results show that the area under cotton and rice increases with the availability of water for irrigation. However, if the government in the long run intends to change the cropping pattern of the study area by introducing crops like cassava and sugarcane which use lower amounts of water with the same net returns as cotton and rice, subsidizing the use or increasing the availability of electrical energy may not be a first best policy.

It is also clear that since cotton and rice are relatively labor-intensive, the demand for human energy increases with the demand for electricity. The com-

plementarity of electrical energy and human energy under uncertainty indicates that a policy that increases the availability of electricity would absorb more labor into agriculture solving, to some extent, the problem of rural unemployment which is prevalent in many of the developing countries. The results show that the increased availability of electricity induces the small farmer to use more animal energy and the medium and large farmers to use more mechanical energy. This is a reflection of the existing pattern of mechanization in the study area, with small farmers using draught animals, medium farmers using power tillers, and large farmers using tractors for primary tillage and intercultivation operations.

Since electrical energy is operation-specific and control-intensive in irrigation (Pingali et al., 1987) among the farms of the study area, the proposed policy may not be useful if the goal of using electricity as a substitute for other energy inputs is aimed at. Similar policies which increases the availability of other energy inputs could be studied to understand the pattern of changes in the cropping systems and the associated demand for other forms of energy under uncertainty. For example, the implications of introducing power tillers through hiring services to solve the problems of labor scarcity during peak seasons of labor demand, namely, land preparation and harvesting could be analyzed using the above framework.

4. Summary and Conclusions

An attempt has been made to explain the risk attitude of the farmers towards various policies of the government using farm survey and time-series data on yield and prices in Tamil Nadu, South India. A mean-variance framework is used to identify the risk aversion level of farmers.

The results of the case study show that farmers in general are risk-averse and the risk aversion decreases with land holdings. Electrical energy seems to be a marginally risk-reducing input, the increased use of which would largely decrease the level of yield uncertainty faced by the farmers. Under uncertainty there exists a strong complementarity between electrical and human energy inputs. Relaxing the constraints on the availability of energy inputs enables the farmers to invest in more risky cash crops. The results support the fact that the crop allocation behavior of the farmers can be explained by the various constraint sets (Binswanger, 1980), availability of electrical energy in our case, faced by them. Policy recommendations should also consider the risk attitudes of the farmers towards their input demand and output supply decisions. It is also shown that the relationship between energy inputs and changes in the input demands and cropping patterns due to various policies can be studied using this framework.

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Appendix

TABLE A1

Ownership of electrical engines and oil engines for irrigation in study area

Ownership	Small farmers	Medium farmers	Large farmers
Electrical engine alone	94	92	84
Electrical engines and oil engines	6	8	16
Two electrical engines per well	0	28	36
Oil engines alone	0	0	0

Source: Calculated from records kept at Block Development Office, Sarkar Samakulam.

TABLE A2

Correlations of variance of crop yields and other determinants of production*

	Rice yield	cotton yield	Sorghum yield	Ragi yield
Electricity supply ^a	0.86	0.91	0.43	0.44
Rainfall ^b	0.67	0.61	0.36	0.47
Nitrogen use ^c	0.71	0.58	0.34	0.31
Incidence of major pest ^d	0.53	0.46	0.26	— ^e

*The variability in yields are based on ten crop cutting experiments conducted in the block each year, 1970–1984 (Assistant Director of Statistics, Coimbatore).

^aBased on supply of electricity during the crop season, 1970–1984 (Block Electricity Office, Thudialur).

^bVariability of rainfall in the study area during the crop season, 1970–1984 (Taluk Office, Coimbatore).

^cVariability of nitrogen use in the crop cutting experiments, 1970–1984.

^dStem borer in rice, boll worm in cotton, earhead bug in sorghum, insect count per m² in crop cutting experiments, 1975–1984.

^eData not available.

TABLE A3

Production function estimates with water and nitrogen as inputs

Cotton yield=	234.18+224.65*water (W)+14.21 nitrogen (N) (1.14) (2.13) (0.518) $-0.18W^2-0.004N^2+0.03WN$ (1.21) (1.48) (1.25)	$R^2=0.863$
Rice yield=	638.14+341.07*W+21.98*N-5.02*N ² (1.25) (4.72) (2.41) (4.57) $-0.64*N^2+0.281*WN$ (3.46) (3.11)	$R^2=0.936$
Sorghum yield=	354.48+134.08*W+9.95N-11.03*W ² (1.32) (2.21) (1.67) (4.50) $-0.08N^2+0.187*WN$ (0.96) (2.98)	$R^2=0.936$
Ragi yield=	247.11+184.00*W+6.47*N (1.72) (3.48) (2.11) $-9.95*W^2-0.78N^2+0.60WN$ (1.97)* (1.28) (1.87)	$R^2=0.871$

Source: Subramanian (1986).

TABLE A4

Variance-covariance matrix of expected net returns of crop enterprises using time series data, 1970-1984

	Cotton	Rice	Sorghum	Ragi (finger millet)
Cotton	694.00	298.10	-118.40	-143.40
Rice		848.23	-169.81	-171.90
Sorghum			364.20	130.42
Ragi				148.83

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