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Modelling and Measuring Economic Efficiency under Risk

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INTRODUCTION

Risk is seen as an important and ever present factor influencing the optimising behaviour of farms adjusting to disequilibria in agriculture (Schultz, 1975). It is manifested in the production process in two ways. One, it affects the level of output by influencing the levels of inputs used, and second, it constrains the firm from realising the full potential of the technology by influencing it not to follow the best method of application of inputs. The former may be described as market (allocative) risk and the latter as production (technical) risk. Although the existing literature on risk seems to have acknowledged the above two manifestations of risk (Kislev and Shchori-Bachrach, 1973; Feder and Slade, 1985; and Feder *et al.*, 1985), most of the studies have concentrated only on modelling the former type of risk (see, for example, Hiebert, 1974; Feder and O'Mara, 1981; Just and Zilberman, 1983; Zilberman and Just, 1984). These studies have basically followed two different approaches to modelling risk: Bayesian and stochastic production function methods.

Accordingly, the results were derived assuming concave and well behaved utility functions and safety-first types of models respectively. These studies were concerned with the adoption of a new technology and generally confined their attention to the gap between the recommended and actual levels of applications of inputs. Thus they concentrated on modelling and measuring the impact of allocative risk on outputs, and therefore, the influence of technical risk, which determines the methods of application of inputs, has not been explicitly studied.

The objective of this paper is to model and to demonstrate empirically how to measure separately the influence of technical and allocative risks on production, using the stochastic frontier production function. Section I discusses the conceptual model of production involving risk and the method of decomposition of risk into allocative risk and technical risk. Estimation procedures are outlined in Section II. Empirical results are discussed in Section III. Section IV presents the conclusions of the paper.

I

RISK: THE CONCEPT

The basic principle in the stochastic production function approach to risk can be summarised as follows: for each firm, there exists a critical minimum threshold income and a maximum income which are possible under the existing technology and the prevailing prices. Firms are not certain about the level of this maximum possible income. They tend to generate a series of income distributions by selecting varying amounts of factors of production (variable factors of production in the short run) with different means and variances. Firms are seen as setting up a very low probability for income occurrence below the threshold levels, and then choosing input levels which would maximise their expected incomes subject

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to the above probabilities. This approach is known as the 'safety-first rule' in the literature. In the context of agriculture in developing countries, it has been demonstrated by researchers that the 'safety-first rule' appears to be a satisfactory approach to modelling risk (Dillon and Anderson, 1971).

Risk aversion can be measured either directly or indirectly. The direct approach, developed by von Neumann and Morgenstern (1944) is concerned with mathematically elucidating answers to some randomly arranged hypothetical questions by different participants. In the indirect approach, the degree of risk aversion is measured using *ex post* production behaviour of firms. Generally, using a stochastic production function with a heteroscedastic error term, yield variability is estimated as a function of inputs (Just and Pope, 1978; Anderson and Griffith, 1981). Random coefficient regression models, in which input response is purely random, have also been used by some researchers to estimate the mean yield level (Huysman, 1983; Smith and Umali, 1985).

Although the 'safety-first rule' discussed by Telser (1956) is more appealing from a theoretical view-point, for empirical estimation, the 'safety-first rule' suggested by Kataoka (1963) provides computational convenience. In Kataoka's approach, the critical threshold of income itself is maximised subject to the above discussed probability constraints.

Let 'h' be the critical threshold of income;

then $$p_r(g \leq h) \leq a \qquad ....(1)$$

where 'g' is the random net income with known mean 'm' and variance 'S^2', and 'a' is the accepted low probability constraint discussed above. For endangered firms with maximum risk aversion, 'a' takes the value zero. Further, 'a' is assumed to be determined by the socio-economic conditions (M) faced by firms:

$$a = f(M) \qquad ....(2)$$

Let $$g = p_y E\,[y(x,z)e^u] - \Sigma p_i x_i\,[y(x,z)e^v] - \Sigma p_i x_i \qquad ....(3)$$

where p_i and p_y are prices of inputs and output respectively; x and z are levels of variable and fixed inputs respectively used in the production of y.

Following Kataoka's approach, maximise 'h' subject to (1).

Based on Chebychev's inequality, equations (1) and (3) can be rewritten as follows (Just and Pope, 1978):

$$h \leq p_y y(x,z)e^{ls} - \sum_{i}^{m} p_i x_i \qquad ....(4)$$

where $l = F^{-1}(a)^{-1}$. This means that maximising 'h' with respect to the probability constraint in equation (1) is equivalent to maximising the upper bound of the critical threshold net income 'h', which is the net random income, $p_y y(\cdot) - \Sigma p_i x_i$.

There is an implicit assumption in many of these risk studies that farms operate without any technical risk and thereby achieve their maximum possible production potential all the time. The recent growing literature on production efficiency shows that the above assumption is not true, which has serious implications for the measurement of risk. It is in this context

$$y_i = f_i(x,z)e^{u+v} \qquad ....(6)$$

where u<0 which denotes firm-specific behavioural characteristics that constrain the i-th firm from realising the potential technical parameters given in equation (5). The subjective parameters of equation (6) are determined by the i-th firm's ability, experience and access to technical information and extension services. When a firm has full technical information, and so does not have technical risk, then u=0 which means that the firm's perceived production function (6) coincides with its potential frontier production function (5).

The objective of the i-th firm is to maximise net returns as follows:

$$E[\pi_i] = p_y E\left[f(x,z)e^{u_i+v_i}\right] - \Sigma p_i x_i \qquad ....(7)$$

Further, equation (7) indicates that the i-th firm's objective function depends on its perception of the potential frontier technical relationship between output and inputs (rather than on the existing perceived relationship), and its perception of both technical and allocative risks. This becomes clear by examining Figure 1.

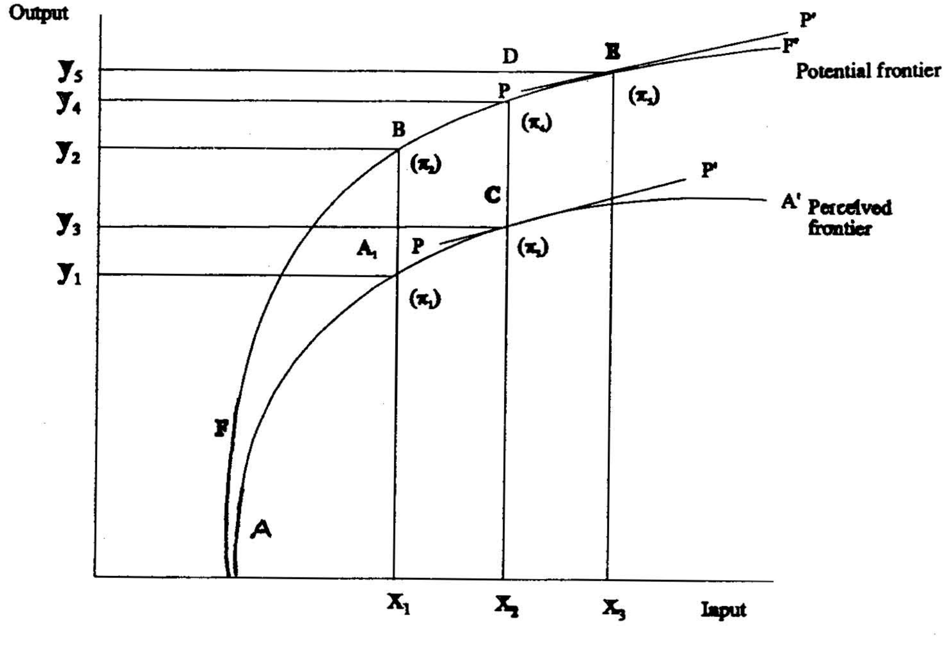

Figure 1. Technical Efficiency and Economic Efficiency With and Without the Perception of Risk

Notes: 1. Figures in parentheses refer to the associated net returns.
2. PP' represents the price situation faced by the i-th firm.

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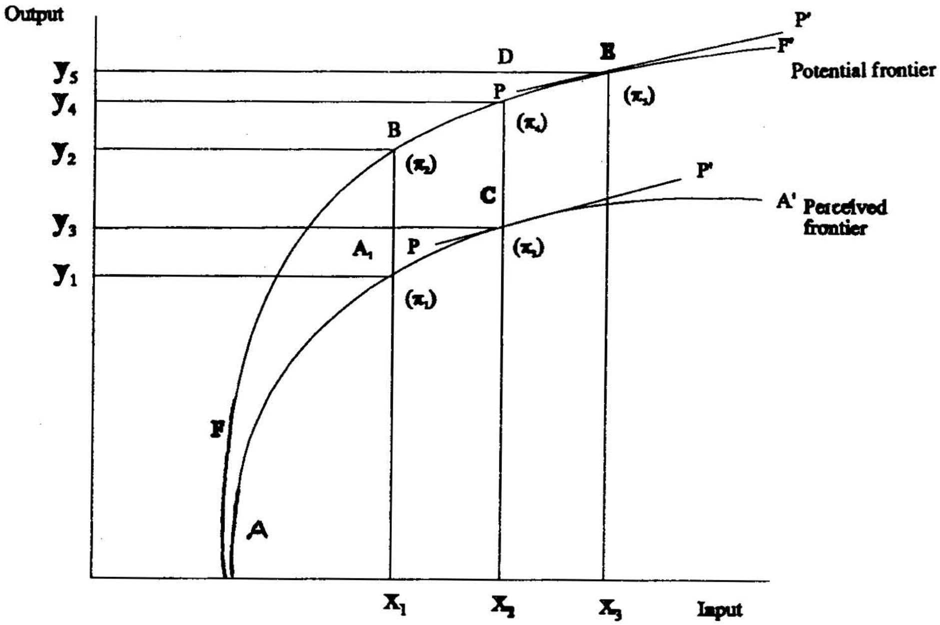

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The interesting question is: what are the losses in economic efficiencies under the influence of perceived risks?

Consider Figure 1 in which FF′ is the potential frontier relationship between output and inputs, i.e., the potential frontier production function, but which is either not known to the i-th firm or is known but is regarded as being risky to achieve. AA′ is the i-th firm's perception of the technical relationship between output and inputs, i.e., its perceived production function with its chosen set of technical practices. When the i-th firm operates at A_1 on AA′, it produces Y_1 by choosing X_1 inputs.[1] The chosen level X_1 is the result of the i-th firm's perception of both technical and allocative risks. The associated net returns π_1, which are realised, incorporate the firm's economic inefficiency in the face of both technical and allocative risks.

If the firm becomes fully aware and confident of the full production potential of the new technology and of the best practices to achieve it, and if the firm has full market knowledge, it can achieve maximum economic efficiency without risk using X_3 inputs to produce Y_5 output and obtain π_5 profits.

A measure of economic efficiency for a firm operating at A_1 can now be defined as follows:

$$EE = \frac{\pi_1}{\pi_5} \qquad \text{....(8)}$$

This measure includes both technical and allocative risks, which are manifest respectively in technical and allocative inefficiencies. Now, the question becomes how much economic efficiency is foregone due to technical risk and how much is due to allocative risk.

If, in the unlikely event, a firm remains totally unaware of its potential frontier, its only option to raise profits will be to improve its allocative efficiency on its perceived production function. It can reach the point of maximum net returns at C, with X_2 inputs, Y_3 output and π_3 profits. This corresponds to Schultz's 'poor but efficient' equilibrium point in traditional agriculture, assuming that the perceived production function is the potential production function.

Typically, the introduction of a new technology creates conditions of disequilibrium. Firms have at least some but imperfect knowledge. Thus a production function such as AA′ can be regarded as transitional, established during the learning process. From a starting point such as A_1, a firm has a number of alternative paths to reach E, the point of maximum economic efficiency on its potential production frontier. With increasing awareness of the technical potential of the new technology and of the means of achieving it, technical risks diminish. First, it is conceivable that a firm could obtain full knowledge of this technical potential, removing all technical risk in the process, and using the existing level of inputs X_1 produce Y_2 output to obtain π_2 profit. Now, a measure of economic efficiency foregone due to technical risk is defined as

$$EE_{tr} = \frac{\pi_2 - \pi_1}{\pi_5} \qquad \text{....(9)}$$

where tr = technical risk.

A measure of economic inefficiency due to the perceived allocative risk is defined as follows:

$$EE_{ar} = 1 - \frac{\pi_2}{\pi_5} \qquad \text{....(10)}$$

where ar = allocative risk.

Second, if the firm is already operating at C, i.e., is without allocative risk with respect to its own perceived production function, using X_2 inputs, the firm could obtain Y_4 output and π_4 profit by moving to the frontier. The measure of economic efficiency due to technical risk will be $EE_{tr} = \frac{\pi_4 - \pi_5}{\pi_5}$ In this scenario, economic efficiency lost owing to allocative risk with respect to its own potential frontier would be as follows:

$$EE_{ar} = 1 - \frac{\pi_4}{\pi_5} \qquad \text{....(11)}$$

where ar = allocative risk.

It appears possible, but unlikely, that a firm would in practice remove its technical risk as described above, without changes in its perceived allocative risk. It may take time for a firm to adjust its operation by moving from its perceived to its frontier production function due to the learning process involved. It is more likely that some relationship will exist between the two efficiencies. The results from earlier studies indicate that as the technical parameters and efficiency increase with knowledge, so does knowledge of the appropriate levels of inputs to use, and thus allocative efficiency increases (see, for example, Kalirajan and Shand, 1992). In other words, as technical risk diminishes, so too will allocative risk. If this relationship does hold in general, then firms are likely to follow paths of increasing economic efficiency over time from A_1 to E (either A_1 to B to D to E or A_1 to C to D to E) which lie between the perceived and the frontier curves.

II

ESTIMATION PROCEDURES

Given the data on actual levels of inputs used, output produced, and prices paid and received, the above measures of technical and economic efficiency with and without risk can be estimated using the maximum likelihood methods. First, it is necessary to estimate the farm-specific potential frontier production function. This requires specification of a functional relationship between inputs and output, and density functions for both the random variables u and v defined in equation (6).

The production process is represented here with a Cobb-Douglas functional form. Alternatives such as the translog and quadratic have been tried but were no improvement over the Cobb-Douglas form in a statistical sense.

It is further assumed that u follows a normal distribution $N(0,s_u^2)$, truncated from above. Both u and v are assumed to be independently distributed for all the observations.

The log-likelihood function for the sample observations Y_i denoted by $L^*(q;y)$, when $q=(b,s^2,l,g)$ is written as follows:

$$L^*(q;y) = \frac{n}{2}\ln s^2 - \frac{n}{2}\ln 2\pi - \frac{1}{2s^2}\Sigma(e-1)^2$$
$$+\Sigma \ln\left[1 - f\left\{\frac{1}{s}\left(-1\sqrt{\frac{1-r}{r}} - e\sqrt{\frac{r}{1-r}}\right)\right\}\right] - n\ln\left[1 - f\left(-\frac{1}{s\sqrt{r}}\right)\right] \qquad ....(12)$$

where $e = \ln y - b_0 - \Sigma b_j \ln x_j$

$$S^2 = s_u^2 + s_v^2$$
$$g = \frac{s_u^2}{s^2}$$

The maximum likelihood (ML) estimator of q which maximises the above likelihood function is obtained by setting its first-order partial derivatives with respect to q equal to zero and solving them simultaneously. Using these estimates, the potential production frontier function can be obtained for each observation in the sample.

Now, the calculations of π_1 and π_2 are done using farm-specific inputs, prices, realised output and the potential frontier output as follows:

$$\pi_1 = p_y y - \Sigma p_i x_i$$
$$\pi_2 = p_y y^* - \Sigma p_i x_i \qquad ....(13)$$

where y and y^* are respectively the firm's realised output and potential frontier output, and x_i's are the levels of inputs used.

The output Y_5 on the true frontier is technically and allocatively risk-free, is both technically and allocatively efficient, and maximises net returns. It is calculated by simultaneously solving the following equations showing the potential frontier function and the profit maximising marginal productivity conditions. Alternatively, these equations can be jointly estimated, after assuming density functions for allocative errors in the marginal productivity conditions. However, with the assumption that technical risk precedes allocative risk, the former method of first estimating the potential frontier and then simultaneously solving the frontier and marginal productivity conditions seems more appropriate.

$$b_1\ln x_1 + b_2\ln x_2 + ... + b_m\ln x_m - \ln y = -b_{m+1}\ln x_{m+1} + ... + b_k \ln x_k - b_0$$
$$\ln x_1 - \ln y = \ln b_1 - \ln p_1 - \ln p_y$$
$$\ln x_m - \ln y = \ln b_m - \ln p_m - \ln p_y \qquad ....(14)$$

There are (m+1) equations in (m+1) unknowns, x_1,.....x_m and y; the production parameters b_0, b_1,.....b_m, b_{m+1},.....b_k are maximum likelihood estimates of the production frontier. The calculated inputs x_1^*, x_2^*, ...x_m^*, x_{m+1},......x_k, represent the levels of inputs which the farm would have chosen had there not been any perceived risk.

Maximum net returns are calculated as:

$$\pi_5 = p_y y_5^* - \sum_{i}^{m} p_i x_i^*$$

where y_5^* and x_i^* are obtained by solving equation (14).

With the calculations of π_1, π_2 and π_5, measures of economic efficiency, economic inefficiency due to technical risk, and economic inefficiency due to allocative risk can be obtained using equations (8) through (10).

III

DATA AND EMPIRICAL RESULTS

The data for the present study were obtained from a cost of cultivation project undertaken by the Tamil Nadu Agricultural University in 1986. A random sample of 64 farmers growing the modern cotton variety MCU-5 in Madurai district, Tamil Nadu State in India was selected for analysis. Cotton is an important commercial crop in India and Tamil Nadu is one of the nine major cotton producing states. The following Cobb-Douglas type of production function was estimated:

$$\ln y = b_0 + \sum_{i=1}^{4} b_i \ln x_i + v - u \qquad ....(15)$$

where y = cotton production measured in tonnes,
x_1 = labour worker days,
x_2 = fertiliser in kilograms,
x_3 = animal power measured in bullock-pair days,
x_4 = area cultivated in acres and multiplied by a soil fertility index. This is assumed to be a fixed input.
u = a technical efficiency related random variable with a normal distribution $N(0,s_u^2)$, truncated from above.
v = statistical white noise with $N(0,s_v^2)$.

The maximum likelihood estimates of equation (15) show all coefficients are statistically significant at the 5 per cent level with theoretically acceptable signs and magnitudes (Table I).

The statistical significance of the inclusion of u in the production function was examined by using the Lagrange multiplier test statistic suggested by Lee (1983). This is asymptotically distributed as an Chi-square with 2 degrees of freedom (equation 15). The computed value of the test statistic is 14.69, which is greater than the critical value (5.99) of Chi-square with 2 degrees of freedom at 5 per cent level. This result implies that u significantly contributes to the variation in y and that the assumption of the truncated normal distribution for u cannot

TABLE I. MAXIMUM LIKELIHOOD ESTIMATES OF THE STOCHASTIC FRONTIER PRODUCTION FUNCTION

Inputs (1)	Parameter (2)	Maximum likelihood estimates (3)
Constant	b_0	4.22 (0.85)
Labour (worker days)	b_1	0.21 (0.07)
Fertiliser (kg.)	b_2	0.14 (0.07)
Animal power (bullock pair-days)	b_3	0.09 (0.04)
Land (acres)	b_4	0.56 (0.14)
	S^2	1.86 (0.58)
	g	0.78 (0.14)
	1	0.64 (0.15)
Log-likelihood	-178.25	
Number of observations	64	

Note: Figures in parentheses are standard errors of estimates.

be statistically rejected for this data set.

The significance of the variance ratio, g, indicates that the sample farmers have not achieved their potential outputs. This result is strengthened by the results of the joint testing of 1=0=g, which is significant at 5 per cent level.

The farm-specific measures of economic efficiencies are calculated as explained above and are given in Table II. The mean economic efficiency, calculated with the influence of perceived technical and allocative risks is 68.3 per cent. Table III shows the amount of economic efficiency foregone due to farmers' technical risk in the form of a frequency table. There is a wide variation in economic inefficiency due to technical risk. The results indicate that about 25 per cent of the sample farmers lost more than 25 per cent of their economic efficiency due to their perceived technical risk. Comparison of column (3) in Tables II and III indicates that a majority of the farmers who have low economic efficiency lost efficiency due to technical risk at high levels. For example, farmer numbers 2,18,21,27,31 and 38 all have low economic efficiency measures between 56 per cent and 60 per cent (Table II). They also appear to bear high technical risks (Table III). This indirectly supports the hypothesis that technical efficiency exerts a major influence on economic efficiency. Low (high) technical efficiency leads to low (high) economic efficiency.

The economic efficiency foregone due to farmers' perceived allocative risk is presented in Table IV in frequency form. The variation in economic inefficiency due to allocative risk appears to be lower than the variation in economic inefficiency due to technical risk. Two observations can be made from these results. First, comparing the results in column (3) in Tables III and IV, it can be argued that there is a high correlation between technical and allocative risk. High (low) technical risk is associated with high (low) allocative risk. For example, farmer numbers 2,18,21,27,31 and 38 have high technical risks (Table III), and they also have high allocative risks (Table IV). Such a relationship is possible because farmers should know their production parameters first, in order to achieve allocative efficiency which involves equating the marginal value product calculated using production parameters with the marginal cost of the inputs. Second, comparing the amount of economic efficiency foregone as shown in Tables III and IV, it may be concluded that technical risk

TABLE II. FARM-SPECIFIC ECONOMIC EFFICIENCY UNDER RISK

Economic efficiency (per cent) (1)	Number of farms (2)	Farmer identification number (3)
56-60	13 (20.31)	2,7,13,18,21,27, 31,33,38,39,49, 62,64
61-65	10 (15.62)	4,8,9,17,22,25,32, 36,40,45
66-70	16 (25.00)	1,10,14,20,29,35,37, 44,48,51,52,54,55, 59,61,63
71-75	12 (18.75)	6,11,19,24,26,30,41, 42,43,46,50,53
76-80	10 (15.62)	3,12,16,23,34,47,56, 57,58,60
80-85	3 (4.70)	5,15,28
Total	64 (100)	

Note: Figures in parentheses are percentages of the total.

TABLE III. FARM-SPECIFIC ECONOMIC EFFICIENCY FOREGONE DUE TO TECHNICAL RISK

Economic inefficiency (per cent) (1)	Number of farms (2)	Farmer identification number (3)
5-10	7 (10.9)	5,15,16,28,30,51,54
11-15	15 (23.5)	1,3,8,12,23,26,34,42, 46,47,50,53,55,61,63
16-20	14 (21.8)	10,14,19,24,29,35,37, 40,41,43,44,57,58,62
21-25	12 (18.8)	6,17,20,22,25,48,49, 52,56,59,60,64
26-30	10 (15.6)	4,7,9,11,13,32,33,36, 39,45
31-35	6 (9.4)	2,18,21,27,31,38
Total	64 (100)	

Note: Figures in parentheses are percentages of the total.

TABLE IV. FARM-SPECIFIC ECONOMIC EFFICIENCY FOREGONE DUE TO ALLOCATIVE RISK

Economic inefficiency (per cent) (1)	Number of farms (2)	Farmer identification number (3)
3-5	13 (20.3)	3,5,8,12,19,23,30, 34,46,47,50,51,53, 54
6-9	16 (25.0)	1,14,16,20,24,28,29, 26,35,37,46,55,57,58, 61,63
10-12	17 (21.9)	4,6,7,9,10,11,15,17, 21,22,25,32,33,41,42, 43,40
13-15	18 (28.1)	2,13,18,27,31,36,38, 39,44,45,48,49,52, 56,59,60,62,64
Total	64 (100)	

Note: Figures in parentheses are percentages of the total.

is the major determinant of economic efficiency. Further, the low levels of economic efficiency foregone due to allocative risk imply that farmers are more or less equating marginal cost with marginal value product calculated from their perceived production functions.

The assumption that risk is an important phenomenon influencing the calculation of economic efficiency seems to be correct. The net gains foregone owing to risk are significantly large overall and vary among the sample farmers.

IV

CONCLUSIONS

In this paper risk was seen as arising principally from imperfect knowledge, first of best practice techniques of the chosen technology, which was termed technical risk, and second of markets, which was termed allocative risk. Utilising the frontier production function model and incorporating risk in the behavioural assumption assigned to the observation-specific random variable u, we have developed a method of estimating firm-specific economic efficiency foregone due to technical risk and allocative risk.

The method was applied to a sample of farmers using a high-yielding variety of cotton in Tamil Nadu, India. It was found from the estimation of the frontier production function that the sample farmers had not achieved their potential outputs on their frontiers. Their mean economic efficiency with technical and allocative risk was 68.3 per cent. On an average, about 20 to 25 per cent of economic efficiency appears to have been lost by the sample farmers owing to their perceived technical risk. Similarly, about 6 to 7 per cent of economic efficiency seems to have been lost owing to their perceived allocative risk. Thus the results of this study suggest that the elimination of both risks with better information on best practices and market conditions has the potential of substantially raising output and profits for the large majority of farmers.

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NOTE

1. Technical efficiency of operating at A_1 rather than at B using x_1 inputs will be $\frac{y_1}{y_2}$, following the existing literature.

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