TECHNICAL EFFICIENCY, FARM PRODUCTIVITY AND FARM SIZE IN INDIAN AGRICULTURE

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Technical Efficiency, Farm Productivity and Farm Size in Indian Agriculture*

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Abstract

Although there is a very large literature on the links between farm size and farm productivity in Indian agriculture there is virtually none that discusses the influence of farm size on technical efficiency. In this paper we try to fill this gap. We use panel data on a large number of farms for two Indian states, Haryana (which has been significantly affected by the Green Revolution) and Madhya Pradesh (where the Green Revolution has had less effect), to estimate a translog production frontier for wheat production and model the determinants of technical efficiency. It is discovered that a separate frontier, of the non-neutral type proposed by Huang and Liu (1994), for each state is needed. In Haryana larger farm size and ownership of land and machines positively influence technical efficiency. This is not thc case in Madhya Pradesh. Thus, with the Green Revolution advancing, policy to increase farm productivity will call for land consolidation and vesting of ownership rights of land and capital with farmers. Several policy conclusions are also advanced.

I. Introduction and Data

The relation between farm size and farm productivity in Indian agriculture has been a topic of intense research for quite some time. The debate was initiated by Sen (1962) who observed a negative relation between the two. Sen offered a general explanation in terms of the low opportunity cost of family labour in a labour surplus economy. According to him, smaller farms use family labour, and use it until the marginal productivity of labour is zero, while larger farms use hired labour, which they employ until marginal product of labour equals the going wage rate. However, the issue of whether the marginal product of labour is, in actual practice, much below the market wage rate generated considerable interest. In the discussion that followed the publication of Sen's analysis, economists ascribed size-productivity differences to the differences in the level of different inputs which can be listed as ranging from the directly quantifiable inputs like human labour, to factors like soil fertility and management which are rather difficult to measure. It was also pointed out that smaller farms have higher intensity of cultivation with more than one crop being grown on the same piece of land. This was offered as an explanation of why smaller farms are observed to have higher output per acre than larger farms.

Biswanger and Rosenzweig (1986) showed that large farms have lower productivity than small farms, the main reason posited for which is that larger farms use more hired labour than do smaller family farms. They argued that family workers are cheaper and more efficient/motivated than hired workers and have more of an incentive to give maximal effort. Although it is true that the problems of using hired labour can be partly circumvented by having rental markets for land, tenancy has its own incentive problems because sharecroppers do not necessarily receive their marginal product. These incentive problems can be overcome to an extent if landowners share the cost of fertilizers and seeds, and tightly supervise the operations of farms and provide the tenant with credit. However, surveys by Barbier (1984) and Otsuka and Hayami (1988) show that tenant cultivated farms have less productivity than self owned ones, though the difference is not as much as expected. Evidence from large collective farms in the erstwhile Soviet Union, strengthen the view of disincentives of using hired labour - and, therefore, that small family cultivated farms may have higher productivity. However, there may be economies of scale associated with agricultural mechanization and with lumpy inputs such as draught animals or tractors. But, even here, an efficient rental markets for machines can partly overcome the economies of scale. Often, rental markets are infeasible for time bound operations, such as seeding in dry climates, or harvesting where climatic risks are high. Farmers compete for first service and prefer their own machines. Rao (1970) showed that the negative relationship between farm size and productivity in northwestern India disappeared with the introduction of tractors. However, he also shows that although economies of scale for machines increase the minimum efficient farm size, this increase is less than proportionate.

The debate then centered around whether the inverse relationship was found only in the aggregate farm management data, the question then was as to whether there was something in the aggregation process itself that gave rise to a spurious statistical relationship. Rudra (1968) studied disaggregated data of **Farm Management Surveys** and compared them with the aggregated tables published in the reports, and concluded that the generalised conclusions drawn do not seem to follow. He, therefore, concluded that the observed negative relation was a result of the process of aggregation. Saini (1979) suggested that Indian agriculture was characterised by constant returns to scale. With returns to scale constant, the explanations for variations in productivity per acre, as farm size changes lies in the levels of various inputs associated with farm size. The higher output per acre in smaller farms is a function of higher input of labour. The analysis suggests that the explanation for the behaviour of net revenue in **Farm Management Studies** lies not in the valuation of family labour at the ruling wage rate but, perhaps, in the productivity of bullock labour and its variations over different size classes of farms.

It has been pointed out that relatively little has been said about the factors determining the farmer's choice of cropping pattern, the number of production cycles, and differentiating land by its fertility. Athreya, Boklin, Djurfeldt and Lindberg (1986) in a field study of Tiruchi district, Tamil Nadu concluded that the size-productivity framework is not necessarily the best measure of scale, their evidence suggests that intensity of cultivation and class status of cultivating households may be more important in this regard. They differentiate between dry area and wet area to take account of fertility considerations and place farmers into four classes, differentiating them by the amount of surplus they generate. They then run a multivariate regression to separate the influence of each of the presumed determinants on productivity.

The results of their study show a significant negative relationship between operated area and value of output per acre at the farm level, but only for land within the wet area. There was no relationship between these two variables in the dry ecotype. The farm level analysis thus highlights the distinct economic structures of the two ecotypes, and the danger of making generalisations regarding the size-productivity relationship without distinguishing between ecotypes. The importance of the distinctiveness of ecotypes seems to have been largely neglected in the farm size-productivity debate.

Even in the wet area, the observed inverse relationship between farm size and productivity disappears at the crop level. It is not a significant variable in any of the crop level regressions reported by Athreya et.al. (1986); crop level results on the other hand confirm the importance of two other determinants which were also at the farm level: intensity and class. It thus becomes clear that the apparent inverse relationship between farm size and productivity at the farm level cannot be interpreted as diminishing returns to scale or the superior efficiency of the small farmer. However, it does reflect the co-existence in the wet area of intensively cultivated small farms, and very few large holdings with a certain proportion of their land left fallow and the rest indifferently cultivated.

Chadha (1978), studied the impact on farm size and productivity after the green revolution experience (which increased the capital inputs component) in Punjab. This analysis suggests that certain factors drive small farmers towards more intensive cultivation, and that small farmers can compete with large ones in all respects except in investment on size based machinery and implements for which farm size alone is the constraint. Further it is concluded that the cooperative movement can help small farmers overcome the constraint created by small size. He considers new technology to consist of both biochemical as well as mechanical innovations. Biochemical innovations have a physiological effect in increasing productivity from a given land base. High yielding seeds, chemical fertilizers, pesticides and regulated flow of irrigation are examples of such innovations. Mechanical innovations have the psychological effect of increasing punctuality of field crop operations. The use of tractor, thresher, drill, etc. are examples of such innovations. While biochemical innovations are generally labour absorbing, land saving and neutral to the scale operation, mechanical innovations are generally labour displacing and biased to scale. Again while biochemical innovations call for a high dose of working capital, mechanical innovations need[1] substantial capital investment. The introduction of these innovations has changed both the quantum and the composition of farm capital, on the one hand and on the other, increased the capital intensity of agricultural production in general. A useful survey of the literature on the relation between farm size and productivity can be found in Sankar (1997). See also Newell, Pandya and Symons (1997).

An important point worth noting is that although there has been considerable work on the relation between farm size and farm productivity, relatively little is known about the determinants of technical efficiency of Indian farms and the relationship of this technical efficiency with farm size. Battesse and Coelli (1992) have studied determinants of farm level technical efficiency for a sample of 38 farms in an Indian village (Aurepalle, in the state of Andhra Pradesh). Apart from the fact that their sample size was small, there is also the consideration that the Battesse-Coelli contribution does not study the relation between technical efficiency and farm size.

In contrast, our data set is much larger. It consists of 282 farms in 20 *tehsils*[2] of Haryana and 378 farms in 55 *tehsils* of Madhya Pradesh. All tehsils in both these states are covered. Hence our data set covers lands of all ecotypes in both these states. The data cover the wheat crops of 1981-82 and 1982-83. The data set also offers considerable contrast since the green revolution has dramatically affected agriculture in Haryana but considerably less so in the state of Madhya Pradesh. Hence, when we analyse technical efficiency in these two states we are able to quantify the impact of the green revolution in this regard. Further, both 1981-82 and 1982-83 happened to be normal years for both Madhya Pradesh as well as Haryana in terms of rainfall. In this paper we estimate stochastic production frontiers for both states and estimate technical efficiency, its determinants and its relation with farm size at the level of individual farms. The source of the data is the latest available **Farm Management Survey** of the Ministry of Agriculture of the Government of India. For the case of wheat data for 1981-82 and 1982-83 for the states of Haryana and Madhya Pradesh were available on a consistent basis.

It is worth noting that when we calculated correlation coefficients between farm size and output per acre for this sample of farms, no clear pattern was discernible. At the level of individual *tehsils*, some correlation coefficients were positive, others negative, only a few were statistically significant. At the zonal level, hardly any correlation coefficients were significant. Since the emphasis in this paper is on technical efficiency, these correlation coefficients are not reported in the paper, but are available from the authors. In Tables 1 and 2 we report some descriptive statistics about the data set.

Tables 1 and 2 here.

The plan of this paper is as follows. In the next section we detail the model used for estimation in this paper. Section 3 presents the results on the estimation of the stochastic production frontier as well as choice of the model used. Section 4 presents the inefficiency estimates and identifies the relation between technical efficiency and, among other factors, farms size. Section 5 draws some policy conclusions.

II. MODEL SPECIFICATIONS

The stochastic frontier production function was independently proposed by Aigner, Lovell and Schmidt (1977) and Meeusen and van den Broeck (1977). The original specification involved a production function specified for cross-sectional data which had an error term which had two components, one to account for random effects and another to account for technical inefficiency. This model can be expressed in the following form[3]:

$$Y_i = x_i\beta + (V_i - U_i), \qquad i=1,...,N, \qquad (1)$$

where Y_i is the production (or the logarithm of the production) of the i-th firm;

x_i is a $k\times1$ vector of (transformations of the) input quantities of the i-th firm;[3]

β is an vector of unknown parameters;

the V_i are random variables which are assumed to be iid. $N(0,\sigma_V^2)$, and independent of the

U_i which are non-negative random variables which are assumed to account for technical inefficiency in production and are often assumed to be iid. $|N(0,\sigma_U^2)|$.

This original specification has been used in a large number of empirical applications. over the past two decades. The specification has also been altered and extended in a number of ways. These extensions include the specification of more general distributional assumptions for the U_i, such as the truncated normal or two-parameter gamma distributions; the consideration of panel data and time-varying technical efficiencies; the extension of the methodology to cost functions and also to the estimation of systems of equations; and so on. A number of comprehensive reviews of this literature are available, such as Forsund, Lovell and Schmidt (1980), Schmidt (1986), Bauer (1990) and Greene (1993).

Work on measuring technical efficiency using panel data became popular with the work of Cornwell, Schmidt and Sickles (1990). They developed an approach to measuring technical efficiency as well as the determinants of efficiency. Typically this involved random effects estimation of the production or cost frontier and then regressed the residuals from this regression on the presumed determinants of efficiency. This methodology was applied, among others, by Kumbhakar (1990), Kalirajan and Shand (1989) and Jha and Singh (1994). This approach, however, makes the implicit assumption that the error terms in the two stages of the estimation are independent of each other. If this is not the case, then the parameter estimates are likely to be inefficient. A single stage estimation which estimates both the frontier as well as the determinants of efficiency would be superior.

Important work toward developing a single stage estimation approach was done by Battese and Coelli (1992) who proposed a stochastic frontier production function for (unbalanced) panel data which has firm effects which are assumed to be distributed as truncated normal random variables, and can vary systematically with time. The model may be expressed as:

$$Y_{it} = x_{it}\beta + (V_{it} - U_{it}) \qquad ,i=1,\ldots,N,\ t=1,\ldots,T, \qquad (2)$$

where Y_{it} is (the logarithm of) the production of the i-th firm in the t-th time period;

x_{it} is a $k \times 1$ vector of (transformations of the) input quantities of the i-th firm in the t-th time period;

β is as defined earlier;

the V_{it} are random variables which are assumed to be iid $N(0,\sigma_V^2)$, and independent of the

$U_{it} = (U_i \exp(-\eta(t-T)))$, where

the U_i are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be iid as truncations at zero of the $N(\mu,\sigma_U^2)$ distribution;

η is a parameter to be estimated;

and the panel of data need not be complete (i.e. unbalanced panel data).

They utilise the parameterization of Battese and Corra (1977) who replace σ_V^2 and σ_U^2 with $\sigma^2=\sigma_V^2+\sigma_U^2$ and $\gamma=\sigma_U^2/(\sigma_V^2+\sigma_U^2)$. This is done with the calculation of the maximum likelihood estimates in mind. The parameter, γ, must lie between 0 and 1 and thus this range can be searched to provide a good starting value for use in an iterative maximization process such as the Davidon-Fletcher-Powell (DFP) algorithm. The log-likelihood function of this model is presented in the appendix in Battese and Coelli (1992).

One can test whether any form of stochastic frontier production function is required at all by testing the significance of the γ parameter[4]. If the null hypothesis that γ equals zero, is accepted, this would indicate that σ_U^2 is zero and hence that the

U_{it} term should be removed from the model, leaving a specification with parameters that can be consistently estimated using ordinary least squares.

The issue of specifying the determinants of efficiency and then estimating these as well as the stochastic production or cost frontier was addressed by Battese and Coelli (1993) who propose stochastic frontier models in which the inefficiency effects (U_i) are expressed as an explicit function of a vector of firm-specific variables and a random error. The Battese and Coelli (1993) model specification may be expressed as:

$$Y_{it} = x_{it}\beta + (V_{it} - U_{it}) \qquad ,i=1,...,N,\ t=1,...,T, \qquad (3)$$

where Y_{it}, x_{it}, and β are as defined earlier;

the V_{it} are random variables which are assumed to be iid. $N(0,\sigma_V^2)$, and independent of the U_{it} which are non-negative random variables which are assumed to account for technical inefficiency in production and are assumed to be independently distributed as truncations at zero of the $N(m_{it},\sigma_U^2)$ distribution; where:

$$m_{it} = z_{it}\delta, \qquad (4)$$

where z_{it} is a $p\times1$ vector of variables which may influence the efficiency of a firm; and δ is an $1\times p$ vector of parameters to be estimated.

In particular we may write

$$U_{it} = z_{it}\delta + W_{it} \qquad (5)$$

where the W_{it}'s are unobservable random variables, which are assumed to be independently distributed, obtained by truncation of the normal distribution with mean zero and variance σ^2_U, such that U_{it} is non negative, (i.e. $W_{it} \geq -z_{it}\delta$). The log-likelihood function of this model is presented in the appendix in Battese and Coelli (1993).

An interesting generalization of this specification was reported by Huang and Liu (1994). They permitted interaction effects between the variables in the stochastic production frontier (the x_{it}) and the determinants of inefficiency (the z_{it}). Thus the frontier itself is subjected to non-neutral shifts. In this case the U_{it} in equation (5) are modified to read:

$$U_{it} = z_{it}\delta + z_{it}^{*}\delta^{*} + W_{it} \qquad (6)$$

where z_{it}* is a vector of values of appropriate interaction terms between the

variables in z_{it} and x_{it} (i.e. z_{it}*x_{it}) and

δ* is a vector of unknown parameters to be estimated.

If the specification in (5) includes, as is typically the case, an intercept term and farm-specific variables and year of observation, which are associated with the vector z_{it}, then the vector z_{it}* in (6), can include the distinguishable products of the input variables (in the case of a production function) in x_{it}, and the firm specific variables and time in z_{it}. Thus the non neutral shifts in the specification described by (6) is a generalization of the case studied in specification (4), with the latter obtaining in the special case when δ* is zero.

III. Estimation of the Stochastic Production Frontier

We use data on 282 farms in Haryana and 378 farms in Madhya Pradesh for the Period 1981-82 to 1982-83 representing all farms which produced wheat in either of the two years. The panel of farms from Haryana and Madhya Pradesh forms our data set. The production frontier estimated was the most general one, i.e., translog whereby output (y_{it}) can be written as:

$$\ln y_{it} = \beta_0 + \sum_j \beta_j x_{jit} + \sum_j \sum_k \beta_{jk} x_{jit} x_{kit} + V_{it} - U_{it} \qquad (7)$$

where the subscripts i and t represent the i-th farm and the t-th year of operation respectively;

y represents the quantity of wheat harvested (in quintals);

intercept has coefficient β_0;

x_1 is ln (Area*10) and carries the coefficient β_1;

x_2 is ln(seed/hectare +0.01)*area (in hectares)[5] and carries the coefficient β_2;

x_3 is the fertiliser input and carries the coefficient β_3;

x_4 is ln of manure input and carries the coefficient β_4;

x_5 is hours of labour input and carries coefficient β_5;

x_6 is ln(beast hours/hectare * area)+1)[6] and carries coefficient β_6.

Cross products are as follows:

[ln area]^2 : the ln of the area squared with coefficient β_7;

[ln seed]^2 :the ln of seed employed squared with coefficient β_8;

[ln fert]^2 :the ln of fertiliser employed squared with coefficient β_9;

[ln manure]^2: the ln of manure squared with coefficient β_{10};

[ln labour hours]^2: the ln of labour hours squared with coefficient β_{11};

[ln beast hours]^2 :the ln of beasthours squared with coefficient β_{12};

ln area* lnseed : cross product of the two variables with coefficient β_{13};

ln area*ln fert : cross products of the two variables with coefficient β_{14};

ln area* ln labour hours: cross product with coefficient β_{15};

ln area* ln beast hours : cross product with coefficient β_{16};

ln seed * ln fertiliser: cross product with coefficient β_{17};

ln seed * ln labour hours : cross product with coefficient β_{18};

ln fertliser * ln labour hours : cross product with coefficient β_{19};

ln fertiliser * ln beasthours: cross product with coefficient β_{20}.

The above stochastic production frontier was estimated for Haryana and Madhya Pradesh separately and for the two taken together. The joint frontier had significantly lower value of the log of the likelihood function than that for either of the individual states. Hence, only the latter are reported in the paper[7].

Efficiency estimates are given as functions of the following:

Dummy variable with value 0 if time period =1982-83 and 1 for 1981-82, with coefficient δ_1;

Dummy variable with value 1 for 1982-83 and 0 for 1981-82with coefficient δ_2;

Area in hectares[8] with coefficient δ_3;

Area squared with coefficient δ_4;

Dummy variable with value 1 if machine is owned by farmer, zero otherwise, coefficient δ_5;

Dummy variable with value 1 if land is owned by farmer, zero if land is leased, coefficient δ_6;

Machine costs with coefficient δ_7;

Dummy variable with value 1 if farm in zone[9] 1, otherwise; coefficient δ_8;

Dummy variable with value 1 if farm in zone 2, 0 otherwise; coefficient δ_9;

Dummy variable with value 1 if farm in zone 3, 0 otherwise, coefficient δ_{10};

ln seeds* Machine costs[10] with coefficient δ_{11};

ln fertiliser* Machine costs with coefficient δ_{12};

ln Beast hours*Machine costs with coefficient δ_{13}.

Estimates of the above equation for Madhya Pradesh showed a certain anamoly in that the sign on area in the production function was negative. This was because of the high degree of multicollinearity between seeds and area. Given the lesser application of green revolution technologies, it seems likely that Madhya Pradesh would show much less variability in seed used for any given area. This finding was, therefore, not a surprise. To tackle this we reestimated the Madhya Pradesh equation with seeds eliminated. For this case, then the coefficient on ln area is β_1, on ln fertilisers β_2, β_3 on ln manure, β_4 on ln labour, β_5 on ln beast hours, β_6 on ln area* ln area, β_7 on ln fertiliser*ln fertiliser, β_8 on ln labour * ln labour, β_9 on ln beast hours * ln beast hours, β_{10} on ln area*ln fertiliser, β_{11} on ln area*ln labour, β_{12} on ln area*ln beast hours, β_{13} on ln fertiliser*ln labour , and β_{14} on ln fertiliser*ln beast hours. The coefficients on the determinants of efficiency are as follows: δ_1 for period 1, δ_2 for period 2, δ_3 for area, δ_4 for area squared, δ_5 on a dummy which equals 1 if machine owned and 0 if machine hired, δ_6 on a dummy which is 1 if land owned and 0 if leased, δ_7 on machine costs, δ_8 on ln fertiliser*machine costs, δ_9 on ln beast hours* machine costs. The last two terms denote interaction effects between the determinants of the frontier and those of efficiency and, therefore, represent the non neutralities.

IV. Results of Inefficiency estimation

In Tables 3 and 4 we present estimates both of the frontier as well as the determinants of inefficiency for Haryana and Madhya Pradesh. For both cases, the translog production frontier provides a satisfactory fit. The non neutral frontier is accepted over the neutral one and results for the former are presented here[11].

Tables 3 and 4 here.

As remarked earlier, in the case of Madhya Pradesh there was strong multicollinearity between area and seeds hence, seeds had to be dropped from the production frontier for this state. For Haryana there was no such difficulty. Factors of production have positive marginal products and a number of these are significant in both cases.

So far as the determinants of inefficiency are concerned, the results are strongest in the case of Haryana. Several facets of the results for Haryana are noteworthy. First, as we move from the neutral to the non neutral frontier, area ceases to be an insignificant determinant of inefficiency and becomes a strongly significant one. Further, the non-neutral frontier performs much better than the neutral one in terms of the likelihood ratio values. The restriction that the interaction terms are insignificant (and, therefore that the non-neutral frontier is not valid) is strongly rejected by the data. Since the coefficient on area squared will, ultimately, dominate that on area, it follows that larger size of farm makes for higher efficiency, although the coefficients suggest that this takes place at large farm sizes. Similarly, ownership of land and machines positively helps efficiency. Further, there are no significant regional variations in Haryana in this regard. It would, therefore, appear that in areas where the Green Revolution has made a significant impact, large size of land holdings and ownership of machines and land should be facilitated to in order to improve technical efficiency.

In the case of Madhya Pradesh, a state which has been less successful in implementing the Green Revolution, the results are strikingly different. Fewer coefficients are significant suggesting that the fit is not as good as in Haryana. Second, area and ownership factors do not seem to have the same beneficial influences on technical efficiency as they did in the case of Haryana. However, the non-neutral model is accepted by the data. The results for Madhya Pradesh indicate that when the infrastructure necessary for the green revolution is deficient there may be less scope for improving the technical efficiency of farms. This might specifically be the case where the scale augmenting technical efficiencies are not present/available and, therefore, incentive effects are a less significant element of inefficiency.

V. Conclusions

The extant literature has emphasised the relation between farm productivity on farm size. In the present paper we provide what we believe to be the first analysis of the effects of farm size on the technical efficiency of farms. The framework used was one of stochastic production frontier analysis with simultaneous determination both of the frontier as well as the determinants of efficiency.

It was discovered that a common frontier for Haryana and Madhya Pradesh in either the neutral or non-neutral variants does not fit the data well. The fact that Haryana and Madhya Pradesh have had such widely varying experiences with the Green Revolution appears to imply that one should have separate frontiers for the two states.

For the case of Haryana, it was discovered that the non-neutral frontier due to Huang and Liu (1994) fits the data well. The restrictions due to neutrality are decisively rejected. Larger farms appear to be more technically efficient. Furthermore, technical efficiency is enhanced by ownership of land and farm machinery. Thus, if the objective is to improve technical efficiency of farms, there are clear cut policy conclusions in the context of areas that have successfully assimilated the benefits of the Green Revolution. In such areas fragmentation of land holdings must be discouraged and steps must be taken to improve ownership of land and farm machinery.

In the case of Madhya Pradesh the results are quite different. This state has not been able to assimilate the benefits of the Green Revolution as Haryana. The fit of the frontier is not as satisfactory, to begin with. Further, the same clear cut conclusions with respect to the effects of size of land holdings and ownership of land and farm equipment as in the case of Haryana, cannot be drawn.

Footnotes

1. Typically, greater application of fertilizers would require higher capital investment.

2. A *tehsil* consists of a group of villages.

3. For example, if Y_i is the log of output and x_i contains the logs of the input quantities, then the Cobb-Douglas production function is obtained.

4. It should be noted that any likelihood ratio test statistic involving a null hypothesis which includes the restriction that γ is zero does not have a chi-square distribution because the restriction defines a point on the boundary of the parameter space. In this case the likelihood ratio statistic has been shown to have a mixed chi-square distribution. For more on this point see Lee (1993) and Coelli (1993, 1994).

5. Hence this is the seed input. The observations on seeds were sometime zero; hence this transformation became necessary. x_2 is to be interpreted as total fertiliser input. This is defined as ln(fertiliser/hectare +0.1)*area). This transformation was needed because observations were sometimes zero. x_3 is to be interpreted as total fertiliser input.

6. This stipulation returns the value "0" when the farm did not use beast hours and the natural log of the number of beast hours where it did.

7. The test statistic is twice the difference of the log likelihood values (the likelihood value for the unrestricted model being the sum of that for the two equations). The computed value clearly supports the separate estimates. This result is not reported here but is available from the authors.

8. The log of area was used in the estimation of the frontier. Hence, using the actual area in the estimation of efficiency since the log is a monotonic but highly non-linear transformation, is justified.

9. We tried to pick up differences in determinants of inefficiency across zones by introducing zonal dummies. These zonal differences are not significant in the case of Madhya Pradesh which, being a larger state, has a larger number of zones. Hence, there are no zonal dummies in the case of Madhya Pradesh.

10. These are interaction effects between the determinants of the frontier and those of Inefficiency along the lines of Huang and Liu (1994). There are three such terms. The same interaction terms were found relevant for Haryana and Madhya Pradesh except the case of seed which was dropped from the frontier for Madhya Pradesh and could not, sensibly, therefore, be included in the inefficiency terms.

11. Results of the neutral frontier for each state as well as the neutral and non neutral frontiers for the two states jointly are not reported here but are available with the authors.

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Table 1

Descriptive Statistics for wheat production in Haryana, 1981-82 to 1982-83

Descriptive Statistics for State1;

x3=production, x4=area, x5=seed, x6=fertiliser, x7=manure, x8=man hours, x9=beasthours

Variable	Mean	Std. Dev.	Skew.	Kurt.	Minimum	Maximum	Cases
X3	4.0157	0.95241	-0.016	2.760	1.099	6.468	546
X4	2.7311	0.95133	0.019	2.452	0.6931	4.984	546
X5	7.3097	1.3669	-2.661	15.569	0.0000	9.582	546
X6	7.6080	1.4908	-2.508	14.259	0.0000	10.23	546
X7	0.98608	12.297	16.891	******	0.0000	250.0	546
X8	8.6832	0.84921	-0.070	2.744	6.427	11.32	546
X9	2.8548	3.2736	0.362	1.276	0.0000	8.732	546

Covariance Matrix

	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	0.90709						
2-X4	0.87523	0.90502					
3-X5	0.92256	0.95523	1.8685				
4-X6	0.98013	1.0097	1.9466	2.2226			
5-X7	-1.1175	-1.3002	-1.0886	-1.1131	151.22		
6-X8	0.75798	0.76195	0.81996	0.85852	-0.64453	0.72115	
7-X9	-0.35098	-0.29505	-0.70748	-0.70935	2.1787	-0.11054	10.717

Correlation Matrix

	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	1.0000						
2-X4	0.96597	1.0000					
3-X5	0.70863	0.73457	1.0000				
4-X6	0.69029	0.71193	0.95523	1.0000			
5-X7	-0.95409E-01	-0.11114	-0.64759E-01	-0.60713E-01	1.0000		
6-X8	0.93717	0.94316	0.70637	0.67813	-0.61719E-01	1.0000	
7-X9	-0.11257	-0.94741E-01	-0.15810	-0.14535	0.54121E-01	-0.39763E-01	1.0000

Table 2

Descriptive Statistics for Wheat Production in Madhya Pradesh

Descriptive Statistics for State2;

x3=production, x4=area, x5=seed, x6=fertiliser, x7=manure, x8=man hours, x9=beasthours

Descriptive Statistics

Variable	Mean	Std. Dev.	Skew.	Kurt.	Minimum	Maximum	Cases
X3	2.9825	0.91105	-0.085	2.891	0.0000	5.282	618
X4	2.5978	0.81578	0.118	2.491	0.6931	4.673	618
X5	7.3208	0.82045	0.153	2.522	5.394	9.473	618
X6	6.1478	2.0585	-2.031	6.783	0.0000	9.172	618
X7	1.2784	5.9320	6.994	66.178	0.0000	75.00	618
X8	8.5510	0.73153	0.083	2.606	6.584	10.43	618
X9	6.3474	2.0365	-2.230	7.517	0.0000	9.142	618

Covariance Matrix

	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	0.83001						
2-X4	0.65014	0.66550					
3-X5	0.66288	0.66255	0.67314				
4-X6	0.96506	0.59130	0.61344	4.2373			
5-X7	-0.44580	-0.27375	-0.28325	-1.1341	35.189		
6-X8	0.58920	0.53320	0.53495	0.73567	-0.20974	0.53514	
7-X9	0.77611E-02	0.25729E-01	0.45445E-02	0.61547E-01	0.57075	0.27085	4.1472

Correlation Matrix

	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	1.0000						
2-X4	0.87477	1.0000					
3-X5	0.88683	0.98990	1.0000				
4-X6	0.51460	0.35212	0.36323	1.0000			
5-X7	-0.82489E-01	-0.56569E-01	-0.58199E-01	-0.92874E-01	1.0000		
6-X8	0.88407	0.89348	0.89130	0.48855	-0.48333E-01	1.0000	
7-X9	0.41831E-02	0.15487E-01	0.27199E-02	0.14682E-01	0.47246E-01	0.18181	1.0000

Table 3
Estimates of Stochastic Production Frontier and Determinants of Inefficiency for Haryana

	coefficient	Std.Error	t-ratio	
beta 0	-3.96375	2.306018	-1.71887 **	intercept
beta 1	0.760752	0.434879	1.749341 **	larea
beta 2	3.757725	0.790693	4.752446 **	lseed
beta 3	-2.82899	0.764166	-3.70207 **	lfertiliser
beta 4	0.001765	0.014228	0.124056	lmanure
beta 5	0.885475	0.613608	1.443063 *	llabour
beta 6	0.026976	0.035575	0.758294	lbeasthr
beta 7	-0.02575	0.010965	-2.3484 **	larea*larea
beta 8	-0.82314	0.155596	-5.29022 **	lseed*lseed
beta 9	0.02486	0.007521	3.305464 **	lfert*lfert
beta10	0.006882	0.048242	0.142656	lmanu*lmanu
beta11	-0.00644	0.004194	-1.53491 *	llab*llab
beta12	0.844469	0.157741	5.353507 **	lbhrs*lbhrs
beta13	-0.79213	0.151416	-5.23151 **	larea*lseed
beta14	0.059279	0.075504	0.785119	larea*lfert
beta15	-0.02661	0.00824	-3.22963 **	larea*llab
beta16	0.753255	0.146828	5.130178 **	larea*lbhrs
beta17	0.033096	0.092647	0.357231	lseed*lfert
beta18	0.005209	0.011458	0.454631	lseed*labhrs
beta19	-0.16054	0.069047	-2.32509 **	lfert*llabhr
beta20	0.001952	0.010518	0.185589	lfert*lbhrs
sigma-sq	0.488799	0.111709	4.375642 **	sigma sq
gamma	0.988951	0.003568	277.162 **	gamma
delta 1	0.22228	0.487227	0.456214	period1
delta 2	-0.01767	0.4967	-0.03557	period2
delta 3	0.077404	0.016961	4.563574 **	area
delta 4	-0.00047	9.78E-05	-4.84584 **	area sq
delta 5	-0.6199	0.131501	-4.714 **	dum lown
delta 6	-2.34342	0.555146	-4.22127 **	dum mown
delta 7	-0.43749	0.034111	-12.8255 **	mach cost
delta 8	-0.09627	0.47204	-0.20394	zone 1
delta 9	-0.12681	0.477341	-0.26566	zone 2
delta10	0.42769	0.465089	0.919587	zone 3
delta11	0.048842	0.005813	8.402245 **	lseed*mac cos
delta12	-0.00652	0.005875	-1.1102	lfert*mac cos
delta13	-0.0315	0.006828	-4.6131 **	l bhrs*mac cos

log likelihood function 180.8472

LR test of the one-sided error = 266.0871

N.B. In the column for t-ratios an asterisk (*) denotes significance at 10%
a double asterisk (**) at 5 %.

Table 4

Estimates of Stochastic Production Frontier and Determinants of Efficiency for Madhya Pradesh

	coefficient	std. Error	t-value		
beta 0	-12.9889	0.966154	-13.4439	**	inter
beta1	2.398476	0.355904	6.739101	**	larea
beta2	-0.01513	0.133063	-0.11373		lfert
beta3	0.010684	0.018056	0.591746		lmanure
beat4	3.542869	0.366709	9.66126	**	llabhr
beta5	0.029048	0.086008	0.33773		lbhr
beta6	-0.04248	0.034033	-1.24806	*	larea*larea
beta7	0.019671	0.004281	4.595157	**	lfert*lfert
beta8	-0.1993	0.03815	-5.22407	**	llab*llab
beta9	-0.02439	0.00792	-3.07946	**	lbhr*lbhr
beta10	-0.01153	0.012481	-0.92411		larea*lfert
beta11	-0.23624	0.060588	-3.89909	**	larea*llab
beta12	0.002234	0.027046	0.082605		larea*lbhrs
beta13	-0.00834	0.026382	-0.316		lfert*llab
beta14	0.00945	0.008657	0.109159		lfert*lbhr
sigma	0.178466	0.026507	6.732703	**	
gamma	0.724979	0.057611	12.5841	**	
delta1	-0.43325	0.282603	-1.53306	*	period 1
delta2	-0.43006	0.277091	-1.55204	*	period 2
delta3	0.006477	0.007375	0.878279		area
delta4	-0.000053	0.000089	-0.6005		area squ
delta5	0.150873	0.123848	1.218208	*	dum mown
delta6	0.590131	0.212001	2.783626	**	dum lown
delta7	-0.01377	0.026843	-0.51313		mac cost
delta8	-0.00186	0.003214	-0.57794		lfert*mac cost
delta9	-0.02149	0.009442	-2.2762	**	lbhrs*lmac cos

Log of likelihood function: -150.276

LR test of one sided error 59.49977

Number of iterations 31

N.B. In the column for t ratios an asterisk (*) denotes significance at 10% and a double asterisk (**) at 5%.