Some Imperatives of the Green Revolution: Technical Efficiency and Ownership of Inputs in Indian Agriculture

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This paper attempts to ascertain the requirements (in terms of ownership of factors of production) for successful adaptation to the Green Revolution in Indian agriculture. We estimate stochastic production frontiers for wheat in two Indian states: Haryana (which has been significantly affected by the Green Revolution) and Madhya Pradesh (where the Green Revolution has had much less effect). In Haryana, but not in Madhya Pradesh, larger farm size and ownership of land and machines positively influence technical efficiency. Thus, with the Green Revolution advancing, land consolidation and vesting of clear ownership rights of land and capital with farmers becomes important.

A country like India, which is overpopulated and has a large proportion of its population engaged in farming, must necessarily depend upon technological progress, in particular of the type associated with the Green Revolution, for food security. At the same time, land reforms have been considered important for poverty alleviation in the rural sector. In this context, it would be important to understand whether the advancement of the Green Revolution is consistent with redistribution of land holdings. More generally, it would be important to understand the requirements of the Green Revolution in terms of ownership of factors of production.

Sen (1962) observed that there is a negative relation between farm size and farm productivity in Indian agriculture. He attributed this negative relation to the higher labor input in smaller farms using family labor, in contrast to larger farms, which employ hired labor till the point where the marginal product of labor equals the wage rate. Smaller farms would use labor till the point where the marginal product of labor is zero, due to the low opportunity cost of labor in a labor surplus economy. This result would then strengthen the case for land reforms.

Later studies, however, show no consensus on this issue. Binswanger and Rosenzwig (1986), Barbier (1984) and Otsuka and Hayami (1988) supported the negative relation. However Rao's (1970) study on Northwestern India found that the negative relationship between farm size and productivity disappeared with the introduction of tractors indicating existence of economies of scale with agricultural mechanization and with lumpy inputs. Rudra (1968) studied the disaggregated data of the Farm Management Surveys and concluded that the negative relationship was a result of the process of aggregation. Athreya, Boklin, Djurfeldt and Lindberg (1986) concluded that intensity of cultivation, class status of cultivating households, cropping pattern, ecotype and fertility[1] of land are more important determinants of farm productivity than farm size. Chadha (1978) attributed differences in productivity between small and large farms to the more intensive cultivation of small farmers.

It is worth noting that the farm size productivity literature has stressed in the main, the (average) productivity of farms and, in some cases, their marginal productivity. Work on efficiency of Indian farms (for reviews see Sankar (1997) and Bat-

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tese and Coelli (1992)) includes Battese, Coelli and Colby (1989) who use frontier methods to study determinants of farm level technical efficiency for a sample of 38 farms in an Indian village (Aurepalle, in the state of Andhra Pradesh) and Kumbhakar and Bhattacharya (1992) who study allocative efficiency of farms (but not their technical efficiency). This literature has very little to say, however, about whether ownership of factors of production (land and capital) helps in improving technical efficiency in the context of the Green Revolution.

The present paper addresses the important question of links between farm size and ownership of factors of production on the one hand and technical efficiency of farms on the other, within the context of large cross sections of farms from two Indian states: Haryana (which has made significant progress with the Green Revolution) and Madhya Pradesh (which has been lagging behind). Differences in the experiences of the two states could be related to the greater impact of the green revolution in one state than in the other. One important objective of this paper is to provide empirical evidence on the variation of the impact of factors (particularly ownership of factors of production) determining technical efficiency across areas with different experiences with regard to the adoption of the Green Revolution technology. As a result we are able to infer whether redistributive policies such as land reforms would lead to higher technical efficiency.

Our data set is the largest that has been used in a study of this type. It consists of 282 farms in 20 *tehsils*[2] of Haryana and 378 farms in 55 *tehsils* of Madhya Pradesh. All tehsils in both states are covered. Our data set covers lands of all ecotypes in both states for the winter wheat crops of 1981–82 and 1982–83. All variables are consistently considered in their net forms. Data for later years are not available. Both 1981–82 and 1982–83 happened to be normal years for both Madhya Pradesh as well as Haryana in terms of rainfall. We estimate stochastic production frontiers for both states and technical efficiency, its determinants and its relation with farm size at the level of individual farms.[3] The source of the data is the latest available Farm Management Survey of the Ministry of Agriculture of the Government of India. In tables 1 and 2 we report some descriptive statistics about the data set.

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

Model Specifications

The stochastic frontier production function was first studied in a cross-sectional framework (see Aigner, Lovell and Schmidt (1977) for example). This specification involved an error term with two components: one to account for random effects and

Table 1. Descriptive Statistics for Wheat Production in Haryana: 1981–82 to 1982–83

Descriptive Statistics

Variable	X3	X4	X5	X6	X7	X8	X9
Mean	4.01	2.73	7.31	7.61	0.98	8.68	2.86
Std. Dev.	0.95	0.95	1.37	1.49	12.29	0.85	3.27
Skew.	−0.02	0.02	−2.66	−2.51	16.89	−0.07	0.36
Kurt.	2.76	2.45	15.56	14.26	12.43	2.74	1.28
Min.	1.09	0.69	0.00	0.00	0.00	6.43	0.00
Max.	6.46	4.98	9.58	10.23	250.0	11.32	8.73
Cases	546	546	546	546	546	546	546
Correlation Matrix							
	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	1.00	0.96	0.70	0.69	−0.09	0.93	−0.11
2-X4		1.00	0.73	0.71	−0.11	0.94	−0.09
3-X5			1.00	0.95	−0.06	0.70	−0.15
4-X6				1.00	−0.06	0.67	−0.14
5-X7					1.00	−0.06	0.05
6-X8						1.00	−0.04
7-X9							1.00

X3 = production, X4 = area, X5 = seed, X6 = fertiliser, X7 = manure, X8 = man hours, X9 = beast hours.

Table 2. Descriptive Statistics for Wheat Production in Madhya Pradesh:1981–82 to 1982–83

Descriptive Statistics							
Variable	X3	X4	X5	X6	X7	X8	X9
Mean	2.98	2.59	7.32	6.14	1.27	8.55	6.34
Std.	0.91	0.81	0.82	2.05	5.93	0.73	2.03
Dev.	−0.08	0.11	0.15	−2.0	6.99	0.08	−2.23
Skew.	2.89	2.49	2.52	6.78	66.2	2.60	7.51
Kurt.	0	0.6	5.39	0	0	6.58	0
Min	5.28	4.673	9.47	9.17	75.0	10.43	9.14
Max	618	618	618	618	618	618	618
Cases							
Correlation Matrix							
	1-X3	2-X4	3-X5	4-X6	5-X7	6-X8	7-X9
1-X3	1.00	0.87	0.88	0.51	−0.08	0.88	0.004
2-X4		1.0	0.98	0.35	−0.05	0.89	0.01
3-X5			1.00	0.36	−0.05	0.89	0.002
4-X6				1.0	−0.09	0.48	0.014
5-X7					1.0	−0.048	0.047
6-X8						1.0	0.18
7-X9							1.0

X3 = production, X4 = area, X5 = seed, X6 = fertiliser, X7 = manure, X8 = man hours, X9 = beast hours.

the other for technical inefficiency. This model can be expressed as[4]:

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

where y_i is the production (or the logarithm of the production) of the i-th farm; x_i is a $k \times 1$ vector of (transformations of the) input quantities of the i-th farm; β is a vector of unknown parameters; the V_i are random variables, assumed to be iid, $N(0,\sigma_V^2)$, and independent of the U_i which are non-negative random variables which are introduced to account for technical inefficiency in production. These are assumed to be iid and $|N(0,\sigma_U^2)|$. This specification has been used in a large number of empirical applications over the past two decades and has been extended in several ways. A number of comprehensive reviews of this literature are available; see, for example, Greene (1993).

Important work on the theory of efficiency measurement within a panel framework was done in the context of the theory of production. For example, Cornwell, Schmidt and Sickles (1990) and Jha and Singh (1994) estimate panel stochastic production frontiers and then regress the residuals from the panel regressions on the supposed determinants of efficiency. This procedure makes the assumption that the error terms in the two stages of the estimation are independent—which is restrictive and may make the estimates inefficient. The method of Battese and Coelli (1993) and others does not involve this restriction since the stochastic frontier, as well as the determinants of inefficiency, are estimated in a single stage. This is likely to improve efficiency considerably. This model can be written as

$$(2) \qquad y_{it} = \exp(X_{it}\beta + V_{it} - U_{it})$$

where y_{it} denotes output of the i-th farm in the t-th year; X_{it} represents a $(1 \times K)$ vector of values, which represent inputs for the i-th farm in the t-th year; the V_{it} are assumed to be independently and identically distributed random error terms which have normal distribution with zero mean and standard deviation σ_v; the U_{it} are non-negative unobservable random variables associated with the inefficiency of farm production, such that, given the X_{it}, the observed level of farm output falls short of potential.

Three different approaches to modeling the determinants of efficiency have been discussed. The first tries to model efficiency essentially as a function of time. The second models efficiency as a function of time and other variables whereas the third (the non-neutral stochastic frontier model due to Huang and Liu (1994)) permits interaction effects between the determinants of inefficiency (Z_{it}) and the X_{it}. In our case, the third model fits well both in terms of (significantly) higher value of the likelihood function as well as the significance of the variables determining farm level output and efficiency.

Concurrently with the stochastic frontier, then, we estimate

$$(3) \qquad U_{it} = Z_{it}\,\delta + Z_{it}{*}X_{it}\,\delta' + W_{it}$$

where Z_{it} is a $(1 \times M)$ vector of explanatory variables, including (possibly) time, associated with the technical efficiency effects, δ is an $(M \times 1)$ vector of unknown parameters to be estimated, δ' is a vector of parameters associated with the interaction terms $(Z_{it} * X_{it})$ and W_{it} are unobservable random variables assumed to be independently distributed, obtained by truncation of the normal distribution with mean zero and variance, σ^2, such that the U_{it} is non-negative. The second model would be a special case of specification (2) when δ' is assumed to be zero; the first model would be a special case of the second model. Models (1) and (2) are estimated concurrently in a single step.

Battese and Coelli replace $\sigma_V{}^2$ and $\sigma_U{}^2$ 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 (1993).

One can test whether any form of stochastic frontier production function is required at all by testing the significance of the γ parameter.[5] If the null hypothesis that γ equals zero, is accepted, this would indicate that $\sigma_U{}^2$ 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.

Estimation of the Stochastic Production Frontier

We estimate a general translog production frontier, whereby output, y_{it}, can be written as:

$$(4) \quad \ln y_{it} = \beta_0 + \sum_j \beta_j x_{jit} + \sum_j \sum_k \beta_{jk} x_{jit} x_{kit} + V_{it} - U_{it}$$

subscripts i and t represent the i-th farm and the t-th year of operation respectively. The dependent variable is log of output and the independent variables are (logs of) area of farm, seeds used, fertilizers, manure, labor hours, beast hours, and the respective cross products. Some transformation of the independent variables was necessary[6] in the final estimation.

The 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 is modeled to depend on the following: dummy variables for the two time periods with coefficients δ_1 and 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 with coefficient δ_5; dummy variable with value 1 if land is owned by farmer, zero if land is leased with coefficient δ_6; machine costs with coefficient δ_7; dummy variable with value 1 if farm in zone[9] 1, zero otherwise with coefficient δ_8; dummy variable with value 1 if farm in zone 2, 0 otherwise with coefficient δ_9; dummy variable with value 1 if farm in zone 3, 0 otherwise with coefficient δ_{10}; ln seeds* machine costs with coefficient δ_{11}; ln fertilizer* 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 anomaly 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 re-estimated the Madhya Pradesh equation with seeds eliminated. The coefficients on the determinants of efficiency are as follows: dummies 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 fertilizer* 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.

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.[10]

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

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

	Coefficent	Std. Error	t-ratio	Variable
beta 0	−3.96	2.31	−1.72**	intercept
beta 1	0.76	0.43	1.75**	In area
beta 2	3.76	0.79	4.75**	In seed
beta 3	−2.83	0.76	−3.70**	In fertilizer
beta 4	0.00	0.01	0.12	In manure
beta 5	0.89	0.61	1.44*	In labhr
beta 6	0.03	0.04	0.76	In beasthr
beta 7	−0.03	0.01	−2.35**	In area*In area
beta 8	−0.82	0.16	−5.29**	In seed*In seed
beta 9	0.02	0.01	3.31**	In fert*In fert
beta 10	0.01	0.05	0.14	In manure*In manure
beta 11	−0.01	0.00	−1.53*	In labhr*In labhr
beta 12	0.84	0.16	5.35**	In beasthr*In beasthr
beta 13	−0.79	0.15	−5.23**	In area*In seed
beta 14	0.06	0.08	0.79	In area*In fert
beta 15	−0.03	0.01	−3.23**	In area*In labhr
beta 16	0.75	0.15	5.13**	In area*In beasthr
beta 17	0.03	0.09	0.36	In seed*In fertilizer
beta 18	0.01	0.01	0.95	In seed*In labhr
beta 19	−0.16	0.07	−2.33**	In fert*In labhr
beta 20	0.00	0.01	0.19	In fert*In beasthr
sigma-sq	0.49	0.11	4.38**	sigma squared
gamma	0.99	0.00	277.16**	gamma
delta 1	0.22	0.49	0.46	period1
delta 2	−0.02	0.50	−0.04	period2
delta 3	0.08	0.02	4.56**	area
delta 4	0.00	0.00	−4.85**	area squared
delta 5	−0.62	0.13	−4.71**	dummy for land owned
delta 6	−2.34	0.56	−4.22**	dummy for machine owned
delta 7	−0.44	0.03	−12.83**	machine cost
delta 8	−0.10	0.47	−0.20	zone 1
delta 9	−0.13	0.48	−0.27	zone 2
delta 10	0.43	0.47	0.92	zone 3
delta 11	0.05	0.01	8.40**	In seed*machine cost
delta 12	−0.01	0.01	−1.11	In fert*machine cost
delta 13	−0.03	0.01	−4.61**	In beasthr*machine cost

Log likelihood function 180.85.
LR test of the one-sided error = 266.09.
N.B. (1) Precise definitions of the variables are as noted in the te at 10%.
(2) An asterisk (*) denotes significance at 10% and a double asterisk (**) at 5%.

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. Taken together with the fact that the less general neutral frontier is rejected on the basis of the λ test, this implies that the non-significance of area as a determinant of inefficiency is a result of mis-specification of the model. Further, 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 quite large farm sizes. Similarly, ownership of land and machines positively helps efficiency. Further, there are no significant regional variations within Haryana in this regard. Ignoring the interaction between determinants of production and those of inefficiency would lead to misleading conclusions. For example, farmers with larger farms and clear ownership titles to them would be more likely to follow cultivation practices that would lead to higher technical efficiency. It would, therefore, appear that in areas where the Green Revolution has made a significant impact, large

Table 4. Estimates of Stochastic Production Frontier and Determinants of Efficiency for Madhya Pradesh

	Coefficent	Std. Error	t-ratio	Variable
beta 0	−12.99	0.97	−13.44**	intercept
beta 1	2.40	0.36	6.74**	In area
beta 2	−0.02	0.13	−0.11	In fertilizer
beta 3	0.01	0.02	0.59	In manure
beta 4	3.54	0.37	9.66**	In labhr
beta 5	0.03	0.09	0.34	In beasthr
beta 6	−0.04	0.03	−1.25*	In area*In area
beta 7	0.02	0.00	4.60**	In fert*In fert
beta 8	−0.20	0.04	−5.22**	In labhr*In labhr
beta 9	−0.02	0.01	−3.08**	In beasthr*In beasthr
beta 10	−0.01	0.01	−0.92	In area*In fert
beta 11	−0.24	0.06	−3.90**	In area*In labhr
beta 12	0.00	0.03	0.08	In area*In beasthr
beta 13	−0.01	0.03	−0.32	In fert*In labhr
beta 14	0.01	0.01	0.9	In fert*In beasthr
sigma	0.18	0.03	6.73**	
gamma	0.72	0.06	12.58**	
delta 1	−0.43	0.28	−1.53*	period 1
delta 2	−0.43	0.28	−1.55*	period 2
delta 3	0.01	0.01	0.88	area
delta 4	0.00	0.00	−0.60	area squared
delta 5	0.15	0.12	1.22*	dummy for machine owned
delta 6	0.59	0.21	2.78**	dummy for land owned
delta 7	−0.01	0.03	−0.51	machine cost
delta 8	0.00	0.00	−0.58	In fert*machine cost
delta 9	−0.02	0.01	−2.28**	In beasthr*machine cost

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%.

size of land holdings and ownership of machines and land should be facilitated in order to improve technical efficiency. Clearly ownership of factors of production seems to be inducing farmers to exert more effort to attain higher technical efficiency.

In the case of Madhya Pradesh, a state that 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 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 is not present/available and, therefore, incentive effects are a less significant element of inefficiency.

Conclusions

The extant literature has emphasized the relation between farm productivity on farm size. In the present paper we provide an 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 both states the non-neutral frontier due to Huang and Liu (1994) fits the data well. In Haryana, 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 to the same extent as Haryana and its growth and yield performance has consistently lagged behind Haryana's. The fit of the frontier is not as satisfactory. 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.

In India the design of agricultural policy is a matter for individual state governments. In the recent past, the governments of Haryana and Punjab, in particular, have made concerted efforts to improve the adoption of new technology by farmers. This has included the provision of credit to facilitate the purchase of equipment and seeds as well as clear demarcation of property rights with respect to agricultural land. Other state governments, including that of Madhya Pradesh, have been tardy in these regards. The analysis in this paper has established that clear ownership of factors of production facilitates the attainment of high levels of technical efficiency in areas where the Green Revolution has been active. Hence, we have been able to identify some areas where governments of states that are lagging behind in the adoption of new technology should concentrate in order to increase the technical efficiency of farming.

Notes

1. Typically, greater application of fertilizers would require higher capital investment.
2. A *tehsil* consists of a group of villages.
3. 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.
4. 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.
5. 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 Coelli (1993, 1994).
6. We used ln of (area* 10) as the area input and the seed input was defined as ln (seed per hectare + .01)* area in hectares. The observations on seeds were sometime zero; hence this transformation became necessary. x_2 is to be interpreted as total fertilizer input. This is defined as ln (fertilizer/hectare +0.1)* area. This transformation was needed because observations were sometimes zero. x_3 is to be interpreted as total fertilizer input. For beast hours the input used was ln (beast hours/hectare* area) +1. 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. In the results tables these are referred to as ln area, ln seed, ln fertilizer and ln beast hour respectively.
7. The test statistic (λ) 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 as are results of the neutral frontier for each state as well as the neutral and non-neutral frontiers for the two states jointly. The choice of functional forms, in the case of both Haryana as well as Madhya Pradesh, was done in the following manner. For each state we began with a general functional form involving, for example, all cross products (in the determinants of inefficiency). The λ test is used to reduce the scale of the model. Thus we are assured that the final functional form chosen is nested within a more general model.
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 de-

terminants of the frontier and those of inefficiency. 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.

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